TRANSACTIONS.

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THE CAUSE AND PREVENTION OF THE DECAY OF BUILDING STONE.

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WITH DISCUSSION.

In the years 1858–59, I had occasion to pass several months in the City of Rodez, the capital and also the cathedral town of the Department of Aveyron, in France. The cathedral was on the line of the Huguenot wars. It showed in every part the mistaken zeal of those religionists, much of whose energy was expended in destroying what was most beautiful. The main doors were a succession of diminishing arches lined with beautifully carved figures of saints in high relief, but every projecting piece that could be reached had been battered with a hammer, so that there was not a head, a leg, or an arm left on the hundreds of figures that formerly ornamented these doors. The cathedral foundations were laid in the eighth century. The building was finished in the last. It is constructed of red sandstone, very like the stone so much used in this city, and is the most prominent building in the vicinity. I had not passed it many times before I noticed that the stone of which it was built was subject to serious decay. It was not long before my attention was attracted to the fact that while the lower part of the church,

which was completed previous to the fifteenth or sixteenth century, had the mouldings and carvings which were left by the Huguenots perfectly sharp; all of the upper part, which was finished later, was almost a ruin.   This was all the more remarkable, because the upper part was completed at a time when what might be called geometrical architecture was the fashion. There were geometrical staircases on every hand, staircases within staircases, lanterns supported on flying buttresses, and almost every other architectural puzzle that was in vogue in those days. It was not long before I noticed the fact that where the stone in any part of the building had a siliceous binding material, neither the mouldings nor the surface of the stone were decomposed; but in proportion as the siliceous binding material decreased in quantity, so also was the stone decomposed, until some parts of the church had actually fallen from decay, and others were in danger. Having occasion to pass the cathedral almost every day for four or five months during different years, I became greatly interested in the study of the decomposition that was taking place in the stone composing it, as also in all the other varieties used in the vicinity. Being obliged to return to America in the year 1860, I noticed the same process of decomposition going on in some of the brownstones of this city, and began almost at once to make some experiments with a view of arresting the decay, some of which were so successful that the building on which they were made had the progress of its decomposition almost entirely arrested, and it would have remained so for some years to come, if the front had not been taken down for alterations two years ago.

In the year 1878, I noticed that the stone of which Trinity Church, in this city, is built, showed serious signs of decay. In the year 1880 it became necessary to undertake a thorough investigation of the causes of this decay, in the hope of learning some means of checking it. The work was placed in my hands. As the examination could not but be a difficult one, I commenced it by making a careful study of all those parts of the church where the stone was decomposed. The fact became evident at once that in almost every place where decomposition had begun, it was immediately under a projecting piece which produced surfaces more or less horizontal. It was apparent at once that at least a part of the decay was due to a defect in the construction of the mouldings themselves, none of them being properly undercut, so that they do not shed rain as they should. In one or two instances imperfect stone was

used in the construction of the church, and in a very few places decomposition has been caused by the position occupied by the stone itself. These studies of the stone in place, and of its decomposition, lasted through several months. I examined the stone inside and outside of the church, as far as it was accessible, high up into the steeple, and became aware that there were used in its construction four different kinds of stone, and that the rate of decomposition was likely to be different in each.

After learning what these varieties of stone were, and the mode of decomposition of each, I selected for examination thirty specimens from all parts of the building, both inside and out, some of which were pieces apparently fresh, and others were scales of more or less thickness, which were easily separated from the stone. A careful physical, chemical and microscopical examination was made of all of these specimens. As the investigation was somewhat extended, and involved the complete review of the whole subject of the decay of building material, and as what has been supposed to be one of the most permanent building-stones of New York and other cities, is undergoing the same decay as other stones in this country, I obtained the permission of the corporation of Trinity Church to publish my results. I have thought that it would be of interest to present to this Society a short review of the whole subject of the decay of building-stone, as well as the investigation of the condition of this particular building. The matter is of all the greater interest at the present time, as not only some of the public buildings, but also monuments, which were designed to last for centuries, are, after only a very few years, showing serious signs of decay.

When we take into consideration what may be found in the air of cities, it is not at all surprising that stones which contain any soluble material should have this soluble portion dissolved in the course of time. The air of any large city may contain carbonic acid, nitric acid, muriatic acid, several different varieties of organic acids, ozone and ammonia. On making some experiments to ascertain the effect of solutions of carbonic acid dissolved in minute quantities in water, it was found that 1 428 parts of a saturated solution of carbonic acid in water were required to dissolve one part of carbonate of lime at zero Centigrade; at 10 degrees Centigrade, it required only 1 136 parts of acid. At a much higher temperature a considerably larger quantity of lime was dissolved. It was also found that dolomite was not so readily

soluble in solutions containing carbonic acid as carbonate of lime. One part of artificial carbonate of magnesia is soluble in 150 to 300 parts of carbonic acid. The mineral magnesite is soluble in 5 071 parts of pure water at 15 degrees Centigrade, with no carbonic acid in it. Artificial carbonate of magnesia, containing three equivalents of water, is soluble in 48 parts. It is also a well-known fact that concentrated solutions dissolve proportionately less than very dilute ones. Carbonic acid is found in the purest air to the extent of about $\frac{3}{100}$ of 1 per cent., and in the air of large cities to three times that amount. It is therefore not at all wonderful that this action of solution should take place in building stone. It is known that nitric acid is generated in small quantities by lightning, and that muriatic acid is frequently found, to the amount of from 1 to $1\frac{1}{2}$ grains to the gallon of air, in localities situated near manufactories or near the sea. Organic acids are sometimes found in the air in considerable quantities; and recent researches[*] have proved that these organic acids will attack minerals which are completely insoluble in ordinary acids, so that it has been proposed to substitute them entirely for the mineral acids in geological work; this is, perhaps, one of the reasons why the silicates in rocks are so easily absorbed by the plants, and will probably account for the ease of decomposition of the minerals contained in the rocks which gelatinize with acids, and also for a considerable amount of the decomposition in the pyroxene and amphibole series.

Messrs. Spring and Roland have recently communicated to the Belgian Academy a series of observations made upon the amount of carbonic acid contained in the atmosphere during a year. They give the result of 266 determinations made in the City of Liege, Belgium; on one side of which there is an industrial, on the other an agricultural district. The average amount of carbonic acid obtained in 10 000 parts of air was 5.1258 parts by weight and 3.3526 parts by volume. These gentlemen remark that this is more than the amount contained in the air of Paris, which is 4.831 parts by weight and 3.168 by volume. The larger amount at Liege is owing not only to the large iron-works there, but also to the fact that the city is surrounded by coal mines. To this the authors attribute the greater heat of the city, as it is well known that a small quantity of carbonic acid in the air causes the absorption and prevents the radiation of heat. They also attribute the cold weather

[*] Annals New York Academy Science, Vol. I, p. 1.

of May to the diminution of the carbonic acid caused by the absorption of it by the growing leaves. Their observations show that a fall of snow will increase the amount to 3.761 by volume, and that in cloudy weather the amount was 3.571 parts, and that there was always a larger amount in winter than in summer. They also found that the quantity was diminished by high winds, but increased with a high barometer; all of which researches go to show that at the very time when the stone is most likely to be acted upon unfavorably—that is, in the winter—there is the greatest amount of carbonic acid in the air. In Liege there are some examples of the decomposition caused by the effect of gases as striking as any that can be seen anywhere in Europe.

The quantity of coal that is burned in the City of New York every year amounts to 4 500 000 tons. If we estimate that this coal contains, on an average, one-half of one per cent. of sulphur, which is an extremely low estimate, this would amount to about 35 pounds of ordinary sulphuric acid per ton of coal consumed, discharged into the air from the oxidation of the sulphur, and would amount in the course of a year to 78 750 tons of sulphuric acid. In this part of the country we burn anthracite, which gives off little else than carbonic acid, carbonic oxide and sulphur. But in regions where bituminous coal is used, ammoniacal constituents are given off as well, and these are corrosive. In order to ascertain how much sulphuric acid could be collected from the rainfall of the city, a funnel and bottle were placed out side the window of the Metallurgical Laboratory of the School of Mines.* The funnel had an opening of 50 square centimeters. It was left exposed during 41 days. At the end of that time it contained 65 cubic centimeters of water. This water was found to contain 4½ milligrams of sulphuric acid. The experiment was not made with a view to catch all the sulphuric acid, but to see if some could be caught. Very many of the days were bright, and the quantity of acid gas thrown into the air must therefore have been many times that amount, although the quantity is very large and sufficiently accounts for the rapid decay going on in the brownstone of that building. It has been estimated that the value of a London winter's smoke, including the carbon which is lost, as well as the other materials volatilized with it, amounts to $25 000 000.

It does not appear that ordinary salt contained in the sea-air, or even

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* This experiment was made by Mr. J. B. Mackintosh.

a considerable amount of sea-spray, has any very deleterious effect upon stone-work, except in so far as it produces a certain amount of other alkaline substances by the action of the salt upon other bases, and in this way becomes, like all other dampness, an agent of decomposition. Almost the only effect of it observable on buildings is its attack on tin roofing, which requires a protection of paint near the sea, while in the interior of the country it will last for years without rusting. A very interesting paper, giving the results of observations made near the city on the quantity of chlorides contained in our rainfall in the year 1884, has been recently published.* It is of great interest in this connection as showing that rain water may be a fertilizing as well as a very destructive agent.

It may be said, as a general rule, that stones are less valuable as they are more porous, for the reason that they are more likely to absorb water containing the gases which attack the ingredients, and also because the water absorbed in freezing, by its expansion tends to disintegrate the stone. It has been said that the act of freezing is equivalent to the blow of a ten-ton hammer on every square inch of surface. Whether this be so or not, the continued expansion and contraction of a porous stone is quite sufficient to disintegrate it, and this disintegration will be all the greater as the stone contains more water. Stones that have already begun to decompose absorb a much larger quantity of water than those which are fresh from the quarry, independent of the quarry water which they contain, and hence the decay will be more rapid as it progresses. Professor Wigner, who examined the obelisk on the Thames embankment, found that the weathered surface of the obelisk absorbed six times the amount of water that was absorbed by the stone which had suffered no decomposition. This, of itself, though small in amount, would be sufficient, in a climate like ours, to produce serious disintegration in the stone.

The builders of the early centuries seem to have understood the injurious action of water, whether as rain, hail or snow, upon their buildings better than we do. Nothing is more striking than the shape of the lintels and sills of their great buildings, which are put in with a sharp incline downward. The architecture of these buildings was carefully studied, even in the minutest detail, and this is not at all strange, since these early masons and builders were a religious fraternity, who studied

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* School of Mines Quarterly, Vol. VI, p. 35.

everything carefully, intending that their monuments, which are mostly churches, should be built to last for ages.

It is very interesting in the history of a country to trace the effects of the building material which its people are in the habit of using, upon their methods of construction. In this country we began with wood, because that was the cheapest material and the most easily obtained. The forms that were adapted to wood, our architects have carried into stone, which is entirely unsuited for them, and hence the constant recurrence of flat surfaces, which retain the moisture and precipitate decomposition, which otherwise might be very slow. It is true that the old Dutch settlers here constructed their roofs to some extent with reference to the great quantity of snow which is the usual accompaniment of the winters of this climate; but their successors have everywhere adopted flat surfaces. It is not generally supposed that these are more deleterious to the stone in countries where there is snow and ice, than rain is in a country where there is only rain, but this is the fact; for where snow is allowed to lodge, the water running through it will concentrate beneath on the surface of the stone, and even when the snow above is not melted, if there is any thawing at all, the snow will be constantly moist on the bottom against the stone. This moisture percolates through the stone. The decomposition under projecting window sills and on the lower side of balconies from this cause, can be noticed everywhere throughout our cities.

There is another cause for the disintegration of stone, which, while it is not very powerful, contributes its share in weakening it, and that is the efflorescence upon or the formation within the stone itself of more or less soluble salts, which are generally sulphates. These, by exuding from the surface, and crystallizing both within and outside of the stone, must of necessity cause a pressure toward the outside, and thus, by producing more or less of a separation in the grains of the stone, tend to disintegrate it. In the modern haste to finish things rapidly, and the anxiety to produce cheap materials, almost everything is done with a view to gain money or to save time, while thoroughness and durability are neglected. The lime of which the mortar is made is burned in direct contact with a refuse fuel, and this contains very frequently considerable quantities of iron pyrites, from which sulphates more or less acid are produced, which are retained in the lime, and as these sulphates are usually more or less soluble, they either effloresce from the mortar,

making it weak and causing it to dissolve out from the joints itself, or infiltrate through the stone and crystallize there, some of the substance ·coming to the outside as a white stain.

There is, independent of this cause—imperfect work in the manufacture of brick—the formation of the sulphates of alumina from the presence of pyrites in the clay. They exist in it much more frequently than is generally supposed. This would form an alkaline sulphate of alumina, containing either potash or soda, and tend to dissever or weaken the brick. Washing these efflorescences off with sulphuric acid, as is frequently done on brick buildings, or the cleaning of the surfaces of limestone in the same way, still further tends to increase the decomposition and consequent weakness, unless the stone or brick be immediately washed thoroughly with hot water, which, however, is never done. The use of acids to cleanse any stone or brick-work is objectionable. There are a number of substances which can be used for this purpose which produce no injurious effect on the brick or stone, and are more effectual, while being quite as cheap as any acid. In underground work the presence of any considerable amount of pyrites in clay should cause extra precaution to be taken with the structure. The brick-work of the first tunnel under the lake at Chicago was crushed in several places, and the tunnel shoved out of place in many more, by the decomposition of the pyrites in the clay, when the work was allowed to remain exposed to the air too long before filling the space between the brick-work and the clay.

The corroding effect of sand carried by the wind at high velocity has a very decided influence in producing the disintegration of the surfaces of building materials. This is evident on the surface of every building which is exposed to the dust of cities and swept by the prevailing winds. My attention was first called to it by being asked to study the reason of the defacement of the inscriptions on certain tombstones of historic interest some years ago, which seemed to be produced by no assignable cause. These tombs were placed just where they received the dust blown by the city winds, through an opening quite narrow, but where the action was constant whenever the winds were of any great velocity. To ascertain exactly what the effect of the power of sand might be when driven by wind, I undertook a series of experiments on the abrasive power of sand, with the sand blast. These were made upon ordinary stones, commencing at first with the softer varieties. I very soon

found that there was no stone of hardness sufficient to resist the power of the blast even for a few minutes. I then tried hard white cast-iron and hardened steel, but found that they had only a small resisting power, and wishing to ascertain exactly what the force of the blast was, in terms which would be readily understood, I commenced a series of experiments on the minerals which compose the scale of hardness. I very soon found that there was no use in experimenting on stones less hard than the topaz. The surface abrasion was so rapid that they were in a very short time reduced to powder, so that there was no opportunity of examining critically the effects of the blast. I very much regret that I did not have an opportunity of examining the effect of the sand blast in regard to the toughness of materials acted on, as well as hardness; but the time during which I was permitted to use the blast was very limited, and I have never had the opportunity of continuing my experiments. I however learned in the course of them, that on soft materials which were elastic, the effect of the blast was either reduced to zero or was very much diminished. It is well known to those using the sand blast that very hard substances may be entirely protected from the effect of the blast by using either a rubber coating or a film of some soft metal like tin, which, from its elasticity, will throw the grains off, while the harder surfaces will be abraded by them. This is no doubt the reason why soapstones and other varieties of very soft rocks, when they do not include within them minerals like pyrites, which, by their decomposition, cause them to disintegrate, have resisted atmospheric influences for very long periods.

I give below a table showing the results of these experiments on the minerals in the scale of hardness, giving the name of the mineral, the time that it was under abrasion, and the weight in grams of the quantity lost by abrasion. The specimens which were subjected to investigation were necessarily small, as I had no idea when I began of the power of the blast. They, however, show conclusively the principle upon which the curious abrasions of rocks over large areas found in the far West, which are the admiration of the geologist and the wonder of the tourist, are produced:

Mineral.	Time under the Blast.	Quantity lost, Grams.
Topaz (Goute d'Eau)................	1 minute	1.9707
" pebble 1	"	2.1499
Emery from Chester, Mass......... 1	"	4.9532
Corundum from Delaware Co., Pa .. ½	"	1.1698
Black diamond.................... 3	"	0.0372
Black diamond 5	"	0.0497
Black diamond 8	"	0.0869

The emery from Chester, Mass., is contained in a considerable quantity of menaccanite and magnetite. A hole was made through the center of the specimen almost immediately, leaving the corundum projecting, but all of its surface was acted upon, though at a different rate from that of the magnetite. The iron minerals were so much softer than the corundum, that they worked out before the corundum had an opportunity of being very much abraded. A conical hole was made in the topaz pebble, which in a few seconds longer would have penetrated it, and the pebble would have broken in two from the increase of the hole towards the sides. The corundum crystal had also a conical hole made in it, large enough to put the little finger through. The face of the black diamond exposed to the blast was originally rough, but became quite smooth at the end of the experiment. A microscopic examination of the surface of each of the specimens showed a surface ground exactly like the rolled surface of stones exposed to abrasion against harder substances in water. There was nothing peculiar about it, except that wherever there was a difference in the composition, there was a difference in the depth of the pitting which is so characteristic of abraded surfaces.

In order to ascertain what the direct application of these facts to buildings might be, I commenced a series of examinations on the composition of the dust of cities. I found it made up of organic material of various kinds and sizes; of very minute, but very sharp particles of iron, mixed occasionally with other metals; and of considerable quantities of clear and very sharp quartz, with some feldspar, together with a few other minerals, such as are found in the paving-stones and dirt of cities, ground to an impalpable powder. After a heavy rain, preceded by high winds, I was soon able to collect considerable quantities of sharp quartz sand, which could be easily studied with a microscope. On a March day we are often made aware how sharp

such sand sometimes is.   When such dust is carried by high winds of a velocity of from 30 to 90 miles an hour, it abrades the surface of all the soft and, after a time, of some of the harder stones, which cannot resist the power of this dust, hurled against it at such high velocities. If the surfaces of some abraded stones are examined with a microscope, grains of a material of a nature quite foreign to those of the stone will be found adhering to it.   This effect is much more prominent in cities than in the open country, as it is there aided by the city gases, but it takes place in the country as well.   I have not unfrequently seen buildings in the open country whose abraded surfaces were due to this cause alone.

These experiments prove the fact, beyond doubt, that even the hardest substance may be abraded by a comparatively soft material hurled against it at a high velocity. I had intended, at the close of these experiments, had I been able to get the use of the sand-blast machine, to gradually reduce the hardness of the sand and increase the velocity of the blast until I should have used flour, so as in this way to study the action of the soft material contained in the city dust upon the stone.   I am satisfied, from many hundreds of observations made on monuments and on the surfaces of buildings, both in this country and abroad, that some at least of the decomposition that is attributed to other causes is due to the action of the winds.   There are many places where the falling out of the mortar between the stones, and the rounding of the corners at that particular point, can hardly be attributable to any other cause.   Usually such stones as these, unless they are very soft, have the abraded surface quite as hard as the rest of the stone, while those which are disintegrated from the loss of any part of the constituents of the stone, whether they are superficial or produced from internal causes, are always easily rubbed into sand.   There are many instances of this character in the sandstones used in some of the old buildings of Europe, the binding material of the grains of which has been entirely siliceous, the stones being worn and rounded in this way so as to produce a very curious effect upon the weather-beaten surfaces.   Independent of the effect of the sand hurled by high winds, it must be taken into account, also, that during violent rains, when the wind is high, the pressure of the wind will force into the stone several percentages more moisture than it would under other circumstances.   If buildings so exposed to the action of rain blown against it by the wind have the usual architectural defects of flat surfaces and mouldings not undercut, the disintegration of the stone composing

them must be very rapid in cold climates. If, in addition to this action of the wind, any part of the binding material is dissolved out by the rain, the decay of the stone will be very rapid, and will be produced usually without any symptom of flaking, because the surface will be worn away before the decomposition has gone far enough into the interior to cause the flaking to take place. The decay, therefore, will generally remain unnoticed.

In the selection of stones for building purposes, too little attention is given to their microscopical characters, and sometimes, when they are so examined, too much stress is laid on phenomena of little importance. It will not do to say that because a rock contains a mineral that has already commenced to decompose, as shown by the examination under the microscope, therefore this stone is valueless. I have, in my collection of microscopic slides, several sandstones, the feldspar in which has commenced to kaolinize, but in which the decay has been arrested. This decomposition undoubtedly took place in these sandstones, which are of triassic origin, previous to the degradation of the rocks which now compose them. When these were ground up, and their elements redistributed to form the sandstone, there seems to have been a cessation of the causes which produced the decomposition, which was arrested, and has not since, so far as we can see, advanced any further in the rock.

The characters which it is important to observe are, whether there are contained in the stone, minerals which are either already decomposed, or are likely to become so; whether these minerals contain water in cavities in considerable quantities; or whether, either by disintegration or by the looseness of the binding material, the stone contains so many interstices or fissures that it is likely to absorb large amounts of water, which may either attack certain of the constituents, causing them to swell, or may itself, under the influence of a severe climate, have sufficient power, in the form of ice, to disintegrate the stone. The examination of the stone in the quarry should be conducted as a whole, and not with reference to a particular part of it, for it not unfrequently happens that stones composed of exactly the same minerals have entirely different properties, as granite and gneiss, for example, and yet one of them may not be a proper stone for outside construction. The age of the stone, since its extraction from the quarry, may or may not be in its favor. Nearly all stones are weaker immediately after their extraction, while they hold the quarry water, than after they have lost it.

Most stones after long exposure, more especially if they have not been uniformly moist, absorb more water than when they are fresh, and are therefore more likely to disintegrate from frost than when they were younger, or than if they were kept uniformly moist. Certain rocks exposed to high heat or to severe cold, lose their power of resistance along irregular lines of weakness, and tend to disintegrate, and this effect may be produced by artificial heating as well as by climate. Stones, therefore, which endure exceedingly well in one climate may not stand in another, as witness the attempt to use in this city certain limestones and sandstones which had stood exceedingly well abroad. The particular place where the structure is to be erected, whether in the city or country, is to be considered. In the city there are noxious and corroding gases, coming either from fuels or manufactories; the dryness or dampness of the ground is to be considered, and whether the particular spot chosen is well ventilated or not; in the country, whether the air is humid or dry, or whether there are prevailing high winds carrying sand. All these, and many other circumstances, have great influence on the durability of building-stones, and should be carefully considered before expensive structures are undertaken.

Building-stones may be divided into three general classes: first, the different varieties of granite and granitic rocks; second, the marbles, which may have a coarse or granular structure, and may be either limestone or dolomite or serpentine; third, the sandstones, which may be composed of material having an organic, an argillaceous, a ferruginous, a calcareous, or a siliceous binding material. Slates are occasionally used in building, but not frequently. They are subject to peculiar forms of decomposition when they are used as roofing material, about which little need be said, because the decomposition which they would undergo in such very thin sheets would hardly take place when they are used in thick pieces in the construction of an ordinary building. Besides these stones, there are a few others which are sometimes used in the vicinity where they are found, such as various kinds of trap or basalt and serpentines; also steatites, and some other very soft rocks. Their use, however, is not common. Each of these stones is subject to its own particular kind of decay, which may be either chemical or mechanical.

Granite is made up of quartz, feldspar and mica, and is considered entirely impervious to moisture, and until the two great fires of Chicago·

and Boston, was believed to be an almost indestructible rock. Recent investigations have shown that it contains within itself many elements of destruction. Of the minerals which compose it, quartz is the only one which is not liable to be represented by several species. While orthoclase is generally the principal feldspar of this rock, it may be replaced in part or in whole by microcline, oligoclase, labradorite or albite. The mica may be muscovite or biotite, and possibly other varieties. The accessory minerals which either accompany it, or in some cases replace almost altogether some one of the regular constituents, are amphibole, pyroxene, epidote, tourmaline, and in certain varieties of Swedish granites, achmite. Of the other minerals, it is estimated that nearly two-thirds of all the known mineral species are found in sienitic rocks. At least ten of these accompany, in more or less large quantities, most granites. These are garnet, titanite, zircon, apatite, magnetite, menaccanite, hematite, pyrite, pyrrhotite and rutile. The variety of the species of feldspar and mica, as well as the way they are put together in the stone, changes both its appearance and its physical qualities. As the quartz is the hardest of the minerals, it might be supposed that it would give its hardness to the stone. This mineral, as it occurs in the interstices between the feldspar, seems to have been formed last. It is everywhere more or less granular and brittle, so that while it is harder than the feldspars, it does not make the rock hard. Crystals which are themselves quite friable, may be separated from it by slight taps of a pointed tool. There is in the School of Mines' collection a beautiful mass of epidote crystals two or three inches long, from New Hampshire, which when it arrived was entirely embedded in quartz, and was separated from it in this way. The feldspars are the minerals which give both the character and the hardness to the rock. This is due almost entirely to the condition of the feldspars, and although the quantity contained in two specimens may be the same, the character of the rock may be entirely different. When the crystals are distinct, and present highly polished cleavage faces, the rock will be hard; when on the contrary, they are lamellar and loosely aggregated, the rock will be soft. Not only are the granites of different hardness, but they possess different rates of expansion under heat, which, as will be shown, is one of the principal reasons for their disintegration. The power of absorbing water is also quite different. The amount of water likely to be absorbed by a well dried granite is a little less than one per cent., but when it has

been exposed a very long time to a hot, dry climate, and has become slightly disintegrated, it will, as shown by experiments made on the London obelisk, absorb several times that amount. This water, and the different rates of expansion of its constituent minerals, is the reason why granite spalls in cases of buildings exposed during large conflagrations. Granites are also of different degrees of fusibility, depending on the quantity and the kind of feldspar contained in them; those containing albite are much more readily fusible than those containing orthoclase, all the more so if the albite is, as it often is, in thin lamellæ. The amount of mica present will also influence both the texture and the durability of the stone. If it is scattered through the rock, about evenly diffused, and not in too large quantities, the rock will be strong, if the feldspar crystals are of the proper character. If it is in bunches it will render the stone weak where the bunches occur. If distributed in directions which are parallel to each other, it may make the rock so weak as to give it a tendency to cleave in the direction of the mica planes.

The presence of hornblende minerals does not seem to affect the strength of granite rocks, except so far as, after very long periods, it is liable to certain kinds of decomposition. It does not generally occur in planes arranged in given directions, and is rather in long crystals of a more or less fibrous nature scattered through the rock. Its fracture is somewhat fibrous, so that it seems rather to tend to consolidate than to weaken the stone. The granites containing hornblende are amongst those which have longest resisted decay and disintegration. It replaces the mica forming the famous syenites which were so much esteemed as building materials by the ancients. When hornblende is replaced by pyroxene, the rock is not durable. Pyroxene is much more brittle and breaks with a much more granular fracture than the hornblende minerals. It does not tend to form fibrous masses, so that the rock is much more brittle than those containing the hornblende minerals. Some New England granites are liable to chip and break, owing to the presence of this mineral, which, whenever it is bunched, is liable to crack out in nodules, or when it is in considerable quantity, evenly distributed, to make the stone brittle as a whole. These two minerals exist together in certain granites which are then all the stronger as they contain less pyroxene. When the rock contains hornblende alone, it is usually very tough. The feldspar present in such cases is almost invariably ortho-

clase, which, as it is the soundest and most permanent of the feldspar family, makes the stone a very desirable one.

It is very generally believed that granite cannot decompose. The kaolinization of the feldspar goes on with exceeding slowness, and except under conditions very favorable to it, would not be likely to have much influence for many years. Not so, however, with the other minerals which compose it. The quartz is often full of microscopic bubbles, carrying liquids liable to freeze by cold or to be transformed into gas by heat, so as to produce a maximum of tension. The least space between the minerals would thus tend to become widened by the lapse of time. When the mica is biotite, the rock is more liable to decay on account of the ease with which this mineral decomposes. When it is present in large quantities, it makes the rock tender from the readiness with which it cleaves. When it is stratified it makes parallel lines of weakness along which the stone splits. The quartz contained in the rock is usually full of cavities, some of which are microscopic, and others macroscopic, which may disintegrate the quartz, either by the expansion of the liquid by heat or cold, and thus render the rock itself more liable to absorb moisture than before. Independently of all this is the general change in the structure of all granites when exposed to very great variations of temperature, which cause minute fissures along the lines of least resistance, which are constantly increased in width and depth, causing the stone to become weakened and finally to disintegrate. This is most frequently seen in granites in which the triclinic feldspars occur, and is most prominent in them when the crystals are large. The rate of expansion and contraction being different in three directions, when the variations of temperature are very great, cause separations to take place along the lines of cleavage of the crystals, which is the line of least resistance, which very soon produces irregular lines of weakness. These are rarely apparent to the eye, and may have been developed to a considerable extent without the possibility of detection, except by a microscopic examination, which is very rarely made. Examples of this are to be seen in the obelisk of Luxor, the one on the Thames embankment, and the one in Central Park, which are disintegrating rapidly, and in a few score of years, if left exposed, will probably be beyond remedy.

The decay which takes place in the granites is either chemical or mechanical. If chemical, it is either the result of the very slow decom-

position of the feldspars and micas of which they are composed, or else of some mineral contained in the granite which decomposes easily, and by its swelling either causes the stone to flake, or by its decomposition to become porous and leave the stone free to be mechanically acted upon by frost and rain. If mechanical, it is the result of the weakening produced along the lines of least resistance by the continued expansion and contraction of the stone where it is exposed either to very great, but gradual changes of temperature, or to sudden ones often repeated. This causes the stone to disintegrate, and is a simple mechanical action without any chemical change. Such weakness has been developed in some granites from this cause, as to produce considerable chipping of the stone in the quarry. It frequently occurs in the granites of New England to such an extent, as to almost convert the exterior of the rock to sand, or to break it up into very small pieces, so that it can be easily removed without blasting. If, in addition to this cause of mechanical weakness, the rock should contain pyroxene, it would be safer to reject the stone. The power of the action of frost is much greater than is usually supposed. It takes a long time for frost to enter any considerable distance into the interior of a stone. When it has once entered, it takes a much longer time to thaw out. I have known of cases where granitic rocks which were quite warm on the outside, where they were exposed to the sun, froze solid, liquid cartridges introduced into the drill-hole to blast the rock. In this case there was the rock in front, which had expanded by the heat at one rate, the rock behind, which was expanded by the frost at a different rate, both forces acting at the same time, both tending to weaken the stone. Such effects do not act to any extent when the stone is in constructions, but it may have acted previous to its being placed there, and have seriously weakened it. Such disintegration takes a very long time; has not been observed to any great extent, so far as my knowledge goes, in the building materials of this country, except in the quarries; and is easily provided against by a careful selection of the stone. It is, however, very common in some of the out-crops of quarries, especially in those granitic rocks which contain a very large proportion of mica, which mineral, as it is very easily cleaved, is always a source of weakness; especially so when it occurs arranged in parallel planes, or contains substances likely to undergo a chemical change. In many instances granites have been discarded by our architects as building

material because they do not resist fire. It is, however, not fair to judge of the quality of a granite by its more or less great fusibility. Granites exposed to the air always contain moisture. All of them are fusible, and all will spall and crack under the influence of such intense blow-pipe heat as occurred in the great fires of both Boston and Chicago. No other building-stone would have resisted those fires any better, for the limestones would have been burned to quick-lime, as they did, and the sandstones would have disintegrated in the same way. There is, however, great choice to be had in the selection of granites, on account of their mineralogical constitution, and the composition of the minerals which they contain. The amount of decay of which they are susceptible is the least of all natural stones, except some of the sandstones which have a siliceous cement. Granite to be used as a building-stone should be of uniform grain, free from dark spots or aggregations of minerals in bunches. It is all the better where there are the fewest number of minerals, especially of the triclinic feldspars or larger mica plates or pyroxene contained in it. It should especially be free from iron compounds, which are likely to oxidize. The decompositions of any kind, whether chemical, physical or mechanical, are very slow, and take place for the most part only in stones which a careful examination would have caused to be rejected from the outset. A good granite will last for ages, but no granite with very large or very irregular sized feldspar crystals, or minerals likely to become oxidized, will last. It may even be said of bricks that when they are improperly burned, or made of a poor quality of clay, they will exfoliate, fall to powder or even be dissolved, while some of the Roman brick-work has stood for two thousand years, and is still in good condition.

Gneiss is formed of the same constituents as granite, and is subject to the same causes of disintegration, only in a much higher degree, as the more or less of lamination, which is due to the arrangement of the mica, causes it to split easily. There is every possible gradation of rock, from a recognizable granite through gneiss to a mica slate, depending on the relative abundance of the different minerals. Owing to the presence of so large an amount of mica, and that it frequently in addition contains a considerable amount of pyrites and other sulphides, it is likely to be a perishable stone. This is seen frequently in the rock of New York Island and elsewhere, where the rock is so soft on the surface that it is frequently possible to remove it to a depth of

several feet with a pick and shovel. Generally, when hard stone is reached after the removal of such a surface, the rock is worthless for several feet below, and will go on disintegrating if put into foundations or structures of any kind. I have seen slabs of gneiss 4 feet long by a foot thick, in retaining walls, so thoroughly disintegrated by the decomposition of the pyrites it contained, that it could be picked to pieces with the nail. These kinds of decomposition are constantly seen in the repairs to the foundations of old houses and sometimes in structures, but generally as such stone is buried it attracts but little attention. In retaining walls, whole sections built in the upper part of this city have become so weak in less than 20 years, that they have had to be rebuilt. It is also liable to exfoliation when set in the structure in such a way that the mica planes are subject to the action of heat. Occasionally, when the plane of the stone is at right angles to the quarry-bed, the quartz, or feldspar, when embedded in mica so that it is on all sides of it, will chip out. Generally, when properly used, if the stone has been carefully selected, it is a durable building material.

It is not generally known that rocks which are hard, and subject to almost no decomposition in one climate, may be thoroughly decomposed to great depth in another. Such a decomposition seems to be going on in the gneiss of New York Island. The water taken from the artesian wells of this city, and of the vicinity, often contain from 12 to 20 grains to the gallon of mineral matter in solution, and some of these, which have been sunk to the depth of 700 feet and over, contain from 6 to 13 grains to the gallon, of carbonate of soda, showing that the rock is undergoing decomposition at great depth as well as at the surface. It has generally been supposed that the brackishness of our artesian-well water was owing to the fact that the dip of the strata is such as to bring towards the center of the island, from both sides, the salt water of both of the rivers, but this could not explain, even if it was true, for such depths the presence of such large quantities of carbonate of soda. I have seen gneiss in North Carolina so thoroughly decomposed over a large area, and to a great depth, that it was soft like clay. In the vicinity of Van Tyne's Station, on the Richmond and Danville Railroad, there is an outcrop of a gneiss rock so decomposed that, while preserving to the eye alone all the characteristics of an unaltered rock, it can be made into balls like clay. This decomposition has been traced to a depth of 250 feet. In the same neighborhood is a trap-dike, over 60 feet wide, so

thoroughly decomposed that it can be shoveled up like dirt, with no indica-
tion that it ever was a rock, except that here and there, there are boulders
10 or 12 inches in diameter with an outside crust like the dirt, but a little
harder, but having the unaltered rock in the center. I traced this dike
for half a mile, and found it everywhere in the same condition. The
railroad cuts through it in one place where the sides of the cut are over
50 feet high, showing the rock thoroughly decomposed from top to
bottom. Such decomposition is quite common in modern volcanic
rocks, and the soils which they furnish are much sought for by the wine
growers.

Mica slate is composed of quartz and mica. It is of necessity lami-
nated, and contains a large number of minerals included within it. It is
fusible, and not very suitable for structures above ground, nor hardly
for those below. The mica is generally biotite. It frequently is so
rotten, from the action of decomposing pyrites, and from the decomposi-
tion of the mica, that it is unfit for anything but gravel. Such material,
when thoroughly rotted, makes good roads and hard walks. It is
sometimes used in buildings, but not often above ground. Its decay is
not very rapid, but is quite sure in time, if the mica predominates, as it
usually does.

Under the name of trap, several varieties of stone are included. As
they cannot usually be got in large pieces, on account of their brittle-
ness, they are used only occasionally for buildings, when they do not
have to be carried any very great distance. They are composed mostly
of a triclinic feldspar, which is often labradorite with pyroxene, peridot,
magnetite, menaccanite, sometimes apatite, and a mica which is gener-
ally biotite. They are almost always accompanied by some form of
chlorite, which is usually a product of decomposition. They are often full
of small cavities which are lined with chalcedony and the zeolitic minerals.
The decomposition seems to be caused by the solution of certain parts
of the rock and a greater or less precipitation of the elements dissolved
in the stone itself. The rock is usually tender and brittle while the
quarry water is in it, and quite tough afterwards. Its decomposition is
exceedingly slow. No great buildings have been made of it, on account
of the impossibility of getting it in large pieces.

Serpentine is a hydrated silicate of magnesia of variable composition,
and associated with a number of minerals of the same general composi-
tion. It is also a product of decomposition of other minerals. It is a

tough but soft stone, and may be in all conditions from roughly lam-
ellar to almost granular. It is associated with chromite and magnetite,
and frequently contains considerable quantities of calcite, and with cer-
tain fibrous minerals, which are sometimes a variety of the rock itself,
and sometimes fibrous varieties of the amphibole series. When it is
contained in calcite it is often used as an ornamental stone. Not unfre-
quently it is associated with the variety of steatite known as soapstone,
when it becomes a serious impediment to the use of the steatite. Both
stones have been used for building, although they are so soft as to be
unsuitable for large structures. They have stood in some places where
they have been used for 150 years; in others they have commenced to
decompose in a much shorter time. This is owing to the variable
nature of the rock, which is rarely ever homogeneous, either in com-
position or structure. When they are quite pure, both steatite and
serpentine, though so very soft, are practically indestructible rocks.
They are not generally, however, suited for use in large cities, on
account of the considerable quantities of carbonates they contain, which
are easily acted upon, and cause the stone both to lighten in color and
to disintegrate on account of them. They can generally only be had
in small pieces, which is objectionable in a building stone.

Under the name of porphyry are included a very large number of
stones which have a compact, generally dark-colored base, with crystals
either of feldspar or of quartz of a different color showing in them.
These are generally either quartz or some kind of feldspar, or both. They
usually occur in dikes. The stone is very hard and tough, and generally
can only be had in small pieces. It has many different varieties of color,
both of base and crystal, and is a very beautiful stone. It was very
much sought for by the ancients, and was extensively used, both for
construction and ornament. None of these stones used in their buildings
show any trace of decomposition, and those found in the ancient ruins
show only a slight diminution of the polish, which, where it was made
very high, seems almost as indestructible as the stone itself. In places,
however, it is quite frequently decomposed. I have seen considerable
quantities of it decomposed to a clay, looking exactly like the unaltered
rock, even to the colors of the crystals, with every ingredient, except
the quartz, turned into a plastic clay, so soft that it could be easily
moulded in the hand. This decomposition has, however, so far as I
know, only been found in situ. The same kind of decomposition takes

place in the conglomerate rocks of Lake Superior, which are porphrytic, when all the constituents of the rock, except the quartz, are sometimes transformed into a soft clay. The entire replacement of the base of the rock by native copper is quite common, both in the conglomerate and amygdaloid rocks of that region.

Slates are little used in construction, both from the difficulty of getting out large blocks, on account of the ease with which they cleave, and also because of the unattractive color which most of them possess. They are sometimes used for building in the vicinity of large quarries, only those pieces, however, being used which do not readily cleave. They must always be placed in their quarry-bed. When placed in a vertical position they are very apt to laminate, but in the quarry-bed they have stood for hundreds of years. Some varieties are subject to a superficial decomposition, which changes the color to an unpleasant yellowish-gray, but it is very slow. When the slate contains pyrites its use must be avoided. Slates cannot be carried far as they are not much esteemed, but they are a durable stone when of good quality, and only objectionable on account of their color. They are used chiefly for roofing purposes, but are being gradually superseded of late years on account of their weight, it being more expensive to build a roof strong enough to support slate than one for a lighter roofing material. In the older parts of the city, where the Dutch traditions were still in force, the roofs were almost invariably made of slate and tile, and placed at an angle of 45 degrees, so as to prevent the accumulation of snow upon them. Tile having been found altogether unsuited to this climate, was abandoned entirely; but slate still continued popular until tin and other materials began to supersede it, as they are now doing to a great extent. It is not ordinarily subject to decomposition, and when this does take place in it, it is usually attributed to the presence of pyrites. I have, however, within a year, seen, on the roof of a house in Massachusetts, rather thick roofing slates, entirely free from pyrites, which were placed there twenty years ago, so decomposed that they will not bear the least pressure, and are broken into small pieces by the force of the wind. This decay is accompanied by a change of color; originally bluish-black, it changes almost to brown. After a little while, such slates will not only be no protection to the roof, but their presence will be an absolute detriment. This form of decay, however, is not found in slates of good quality, and is more of a lithological curiosity than a real danger to be guarded against.

Slate was formerly much used for ornamental purposes, and where that of good quality was selected it answered perfectly well, as it is capable of receiving very high polish.   Owing, however, to the difficulty of securing a slate which was compact and hard, this use of them seems to have been abandoned.   They are, however, still extensively used to make enameled surfaces for interior decoration.   The old graveyards of New England contain many tombstones of slate dating back nearly to the close of the seventeenth century.   Most of the slate headstones in Trinity churchyard are to all appearances entirely unaffected, and seem to be as strong and perfect as on the day they were placed there. Two of these were erected in 1691 and 1692, on the north side of the church, and were cut on both sides.   One of them, that of 1691, shows no sign of deterioration, except an occasional spalling of very small pieces ; the inscription is quite sharp.   The other is very much broken on the lines of pseudo-cleavages, produced by pressure; but the surfaces of fracture, though produced many years ago, are quite fresh.   The faces of both these stones are somewhat gray from alteration.

Of the different varieties of marble, those which are granular are the ones which are generally most easily attacked, and of the limestones and dolomites, the former seem to be most readily acted on, while those marbles which are composed of a mixture of limestone and dolomite, are very easily affected by the weather, the limestone going first and leaving the dolomite.   Most of this weathering takes place on buildings in the country, or standing by themselves, by the decomposition of the minerals contained in the interior, which can easily be prevented by proper selection of the stone.   Where the buildings, however, are in a confined space, especially in large cities, the action of the city gases is such as to attack the limestone, leaving the less easily affected dolomite altogether uninfluenced at first, and afterwards, according as there is more or less of lime present in it, causing it to crumble, or leaving a very rough surface.   There are a number of notable examples of this decomposition in some of what were once the most beautiful tombs in our city churchyards, which have literally fallen into sand by the solution of the lime by the city gases.   The commencement of this action may be seen on the monument to Alexander Hamilton in Trinity churchyard, and on the Emmet monument in St. Paul's.   The same action is frequently seen in the dolomite quarries, as at Lee, Mass., where the limestone is dissolved out, leaving the dolomite as a sand with crystals of tremolite lying loosely in it.

The churchyards of the country also are full of stones undergoing this kind of decay; which, however, progresses much more slowly there than in the city. One of the most remarkable instances of decay of stone can be seen in the southern division of Trinity churchyard, near Broadway, about half way between the church and Rector streets, in the shape of a square marble monument with an inclined top now about four feet high. Originally this was twelve feet high, supported on polished columns, with an open space underneath, in the center of which was an urn. This monument was erected in the year 1820 to the memory of Grace Lyde. It was made of highly polished marble, and when it was put up, was one of the most beautiful and graceful monuments ever erected in any of our city churchyards. In the year 1860, the name on the monument had already become illegible. About five years ago it was in danger of falling, and an order was given by the church authorities to repair it. It was found, however, that the stone was so badly decomposed that it would not hold together under the pressure of its own weight, so that the monument could not be repaired. It had to be taken down. All of it that could be used was put up in its present shape. The decay has still further progressed since then. The stone is so soft that it easily crumbles between the fingers, and it is rapidly falling into sand. The inscription has entirely disappeared, and in a few years longer nothing will be left of it but sand. The Capitol, at Frankfort, Ky., was built in 1837 of a very fine-grained limestone, with some excess of carbonate of magnesia. This has become acted on, so that the building is completely coated with what appears to be a very fine wash, which is very adherent, but can be easily scraped off with a knife. It consists of carbonate of lime. The interior of the stone has suffered no decay.

As a general rule when a limestone contains much pyrites it should be discarded, but it does not always follow as a necessary consequence that the presence of pyrites in stone is of necessity a disadvantage. As a general rule the presence of marcasite is. Of the ordinary pyrites some varieties do not decompose, while others do; the presence of such varieties as decompose may disfigure the stone, if in small quantities only, or may cause it to swell and disintegrate if in large quantities. In compact stones its presence has but little influence; in porous ones it is generally objectionable. But no absolute rule should be laid down, for, while as a general thing it is to be avoided, it may be harmless. In gen-

eral it may be said that the presence of much pyrites makes the stone unfit for use in the exterior of buildings. It is often a matter of surprise that some limestones do not stand here, either in houses or in graveyard monuments, for any great length of time, while they have stood for thousands of years both in Italy and in Greece. This is, however, very easily explained, from the fact that in these countries in the situations where they have stood, the air is comparatively dry, and also does not contain so much, if any, of the injurious gases which affect our stones. In looking over our churchyards—Trinity, St. Paul's, St. John's, and Trinity cemetery—we find that the effect of weathering upon the marble is very curiously developed. If the stone is placed vertically, according as it is more or less compact, or is composed entirely of carbonate of lime, or partly of lime and dolomite, the polish on the stone will be very much deteriorated in the course of ten or fifteen years, and may, on certain stones, sometimes be entirely gone in less than that time.

There are many stones in Trinity and St. Paul's churchyards, placed there within the century, where the inscriptions have been entirely obliterated, leaving in their place a very rough surface, which scarcely shows any trace of the stone ever having been worked. In Trinity cemetery, at One Hundred and Fifty-sixth street and North River, where the air is much purer than it is in the city, some of the marble headstones have become so rotten after twenty years' exposure, that they will not bear their own weight, and crumble from the least friction, even of the hand. As a general rule the finer the texture and the closer the crystals are arranged in the stone, the less this disintegration has taken place. The monument erected in 1814 to the Sieur Rochefontaine, who commanded the French forces during the Revolution, was so far decomposed, that in the year 1885 the inscription was recut by order of the Corporation of Trinity Church. The monument not far from it, erected to G. F. Cook, the famous actor, by Edmund Kean, in 1821, was repaired by Charles Kean in 1846, and again by E. A. Sothern in 1874. Except on the south side, the inscriptions are now very much defaced. It was necessary to recut the inscription on the monument to Alexander Hamilton in Trinity churchyard, in 1885. The monument to Alexander Bradford, New York's first printer, erected in the year 1752, was so far defaced and crumbled, that in the year 1868 the Corporation put up a *facsimile* of the original stone. This is so far acted on already that sand

can be brushed off of its surface with the hand. The inscription on the altar tomb near that of Alexander Hamilton, in Trinity churchyard, is so far defaced, from the solution of the stone, that only a slight depression, where the lettering once was, can be distinguished on the surface of the stone. As the result of the examination of the New York City cemeteries, I am confirmed in the opinion that, in general, limestone, whatever its character, is entirely unsuited in this climate for the construction, in cities, of monuments which are to be exposed to the air. One of the most remarkable destructions of this kind which has ever come within my observation is that of the cathedral at Douai, in France; the whole of the outside coating of Caen stone of this church is gone, leaving nothing but the filling of brick and rubble to support the interior of the church. It is said that the whole of the outside of Westminster Abbey has already been replaced twice, and will soon have to be replaced a third time. The exterior of Cologne Cathedral was hardly finished before they commenced to repair it. Notre Dame, and the Tour St. Jaques, in Paris, require constant attention and repair.

The rate of disintegration in such stones used for buildings can be very much lessened by filling the pores of the stone where decay has already commenced, or previous to its being put into the building, with some substance like oil, paraffine, or sulphur. In the case of the experiments that have been tried upon the Houses of Parliament, it has been found that sulphur in solution has answered better than any of the other substances used as a remedy against this decomposition. It has also been found that the filling of the pores of that stone is generally useless if it has been done on the outside only. I saw several cases where the pores of the surface only of the stones, having been filled with sulphur, had retained their surfaces during twenty years of exposure, and were only just beginning to exfoliate. Where the remedy has been applied to the six sides of the stone previous to its being put into the structure, it seems to have been effective, such stones, after ten or fifteen years of exposure, showing no signs of decay.

Almost everything has been tried on the Houses of Parliament, but nothing as yet has been found to be successful. This is owing partly to the fact that a large proportion of the stone was unfit to put into any building under any conditions. The Commission which selected the quarry from which the stone should be taken was discharged when their

report was made, and no one was responsible for the stone selected after this quarry was found to contain an inadequate supply; and when it failed, stone was obtained almost anywhere that it could be had. The destruction has been so rapid, and the decomposition of their highly ornamented surfaces has extended so far, that in the case of finials and the small pinnacles which they surmount, they are now replaced by cast-iron painted the color of the stone.

From want of care in its selection, I have seen the *calcaire grossière* of Paris decompose so rapidly, that the stones had to be removed after a few years. Up to 1860 there were on the side of the Louvre next the Seine, between the passages that enter the Place du Carousel next the Tuileries, large stones which had fallen entirely into sand to a depth of over 6 inches, and the remaining portion was so soft that it could be picked to pieces with the finger-nail. This same decomposition took place also in certain sandstones with a calcareous binding material, which was much used in Paris at this time. I have often gathered fossils in the sands of the quarries from which both these kinds of stone were taken, certain beds of them on the outskirts of Paris being the favorite resort of fossil hunters. In this case there was both the original want of consolidation of the stone and subsequent decay to make it weak.

The silicates of soda and potash with which the surface of the Louvre in Paris was washed in 1858, seems to have been quite effectual. In this case a silicate of lime was formed, which has protected the surface from further action of the weather, but on the Houses of Parliament, owing to the bad quality and the extremely soft and porous nature of the stone, which required that the pores should be filled at the same time that the surface was indurated, it does not appear to have been successful.

Some years ago attempts were made to introduce Caen stone into this country, as it had proved so satisfactory in many buildings in England and France. A number of houses of this stone were erected both in New York and Brooklyn. About the same time the interior of Trinity Chapel on Twenty-fifth and Twenty-sixth streets was lined with this stone. In less than ten years the Caen stone used on the outside of buildings in Tenth street, between Fifth and Sixth avenues, began to exfoliate, and the fine carving crumbled to pieces before anything could be done to preserve it. The rest of the front of some of these buildings

has been preserved till this time only by keeping it constantly and carefully painted. To be effectual, this paint must be renewed every four or five years. The interior of Trinity Chapel, however, shows no trace of decomposition of any kind. The stone is a little clouded with dirt, but otherwise is apparently as sound as the day it was erected, showing that Caen stone is perfectly suitable for interior decoration when kept dry. Soft stones of this character can only be used in outside work in large cities by being kept constantly coated with paint.

It is not an uncommon thing where the dolomite and limestone are mixed together, in slabs that have been highly polished, to have the limestone filling between the crystals eaten out by the gases when they are placed in confined places in cities, which leave the dolomite crystals projecting, so that the surface looks as if it never had been polished. An excellent example of the commencement of such decay can be seen in the altar tombstones near the south entrance to Trinity Church, and in the Emmet monument in St. Paul's churchyard.

An extremely curious phenomenon sometimes takes place from the elasticity of limestones, which seems to threaten the immediate destruction of the stone, but which it may resist for a very long time. It is not confined entirely to limestones, but occurs in sandstones as well. This is the bulging of the stone owing to heat applied entirely on one side. From the constant expansion of the surface the crystals seem to assume a certain degree of mobility among themselves, so that the stone bends outward if placed in a vertical position, or sags, if there is opportunity for it, when placed horizontally. This phenomenon has been noticed in some of the public buildings in Europe, but has not attracted much attention here. Having occasion many years ago to examine into the cause of a smoking chimney, I found the opening at the top almost entirely closed by the sagging of the cap, which was a piece of dolomite 3 feet 6 inches square and 2 inches thick. I had it turned over with the bulged side up. In the course of another six months it had commenced to bend in the other direction. The next year it had to be turned over again, and after two or three turnings it finally broke. The heat of the fires on the under side had produced such a separation between the crystals as to cause their movement, and the successive bendings had weakened the stone so that it no longer had sufficient resistance to bear the strain of bending. In buildings the danger of bulging is

only that of throwing the stone out, as the expansion is on one side only, and as it can never occur except when the stone is used in thin slabs for facings, can always be provided against by the way in which the stone is fastened into the wall behind it. This same phenomena is often seen in altar tombs where the slab is not sufficiently supported in the center. It is most common in the coarse granular limestones, or those composed of mixtures of calcite and dolomite. Some such tombs can be seen both in Trinity and St. Paul's churchyards, which are so hollow in the center, that they hold sufficient water for the birds to bathe in. On most of such stones the inscription has been entirely obliterated. I have sometimes seen sandstones which had laminated in thick layers, from the solution of their binding material, curl away, by the heat of the sun, several inches from the stone behind them, in sheets over eighteen inches wide, and keep bending until they could no longer support their own weight.

Certain conglomerates, which are very hard when extracted from the quarry, undergo a more or less rapid decomposition when exposed to the air. Such conglomerates as these, composed mostly of quartz or limestone grains cemented together by an argillaceous material, are quite frequent in the coal formation, and are, of course, utterly unsuited for building material. There are, however, other limestone conglomerates, notably some of those breccia which are used in the public buildings of Washington, where the disintegration, though much slower, is none the less effective. The beautiful colonnade of the Treasury Department on Fifteenth street, in Washington, is made of Potomac marble, which is such a material as this. Some years before the war, the disintegration of this stone had progressed so far, that the complete destruction of the colonnade was threatened, so that it became necessary to prevent its extending further. It was coated with paint, and has been carefully protected in this way ever since. It is not generally known that the front of the old Capitol building and also of the White House, which are limestones, commenced to disintegrate so seriously that they were painted some forty years ago, and have been kept painted ever since. The same decomposition is taking place in some of the beautiful marble used in the decoration of the Chapel of Durham Cathedral.

Sandstones are generally supposed to be composed of quartz sand, cemented together by different kinds of binding material, such as quartz itself, as is the case with the Potsdam sandstone; with oxide of iron, as

in some of the sandstones of New Jersey and Connecticut; and with carbonate of lime, with or without oxide of iron, as is the case with most of the stone of Trinity Church, and of the ordinary brownstone which is so extensively used in the construction of the fronts of our city houses. In some cases clay is the binding material of the sand, and in others it appears to be some organic compound which easily decomposes.

When the material of which the stone is composed is fine, it is called a sandstone; when it is coarse, it is called a conglomerate. When the pieces are of the size of a hickory nut, and, as is frequently the case, of various colors, it is called a pudding-stone. When the pieces are angular, it is called a breccia. Where such siliceous rocks have undergone metamorphic action, they are frequently changed to quartzites. I have often seen a fine-grained quartz sandstone, under the prolonged action of heat in a furnace, without however melting, turned into a nearly compact quartz, with a glassy luster, having very much the aspect of a glazed porcelain. A striking example of this phenomena is in the metallurgical collection of the School of Mines. From a simple inspection there does not seem to be the slightest relation between the stone before and after metamorphism. The stones, however, that are composed altogether of quartz, are of rarer occurrence than is generally supposed. The materials making up the rock are of variable composition, and include a great variety of minerals which seem to have come from previously existing rocks, which have been ground up and subsequently cemented together. In most cases the minerals contained in the stones have retained the characteristic qualities that they had in the original rock. The microscopic bubbles can still be seen moving, as they have been doing since the ages of their formation. The feldspars retain their characteristics, and the fact that the rock of which the sandstone was formed was sound, or was undergoing decomposition at the time of its destruction, may still be seen in the sandstone.

The structure of the stone is very different, not only from the different kinds and sizes of the grains which compose it, but also according to the greater or less amount of pressure exerted at the time of its formation. In some, the consolidation is so loose that they are manifestly unfit for constructive materials; in others, there is every degree of real or apparent compactness. In order to fix a rule, it has been stated that those stones which, in a climate like our own, effervesce slightly with acids, weigh less than 130 pounds to the cubic foot, and which absorb

in the course of twenty-four hours over five per cent. of water, cannot be good stones. Many of our sandstones, after having been exposed to the weather for a considerable length of time, will absorb anywhere from three to fifteen per cent. of water in twenty-four hours, and consequently stand but a short time in a building.

When sandstone, which has a laminated structure, is not placed in its quarry bed, it is impossible that it should stand in the building for any great length of time, unless the binding material is quartzose. Sooner or later, from the effects of the weather, lamination will take place, and this may be seen in most of the sandstone pillars so common on the fronts of houses in former days, and on some of the ornamentation of the beautiful entrance to Greenwood cemetery, which is being rapidly destroyed in some of its upper parts by this cause, as well as decomposing from other causes in other parts of the structure.

Decomposition occurs most rapidly in those sandstones having organic or argillaceous binding materials. The former are decomposed by the weather, the latter very rapidly swell and disintegrate the stone, and very soon obliterate all traces of mouldings. Those having a ferruginous gangue are more suitable, unless the iron has come from the decomposition of pyrites, in which case the excess of sulphur renders the stone likely to disintegrate. In some cases the causes which have produced the precipitation of the iron, which binds the sand together have acted very unequally, so that the stone is hard in some places and soft in others, and consequently resists the action of pressure unequally in different parts.

Most of the New Jersey sandstone has either an argillaceous or calcareous binding material. Both are easily acted upon by the weather in the country and by the gases of the city, especially at points near the ground, or where the mouldings are improperly cut, so that the water is not shed from, but remains on or filters through them. Examples of this may be found in almost every street in large cities where brownstone is used. The same kind of decay may take place at or above the level of the ground from a different cause. If the superstructure has not been provided with a damp course, the moisture will rise in the masonry as high as 8 or 10 feet, the effect being the more prominent as the walls are thicker. If, in addition to this, the surface drainage is toward the building, instead of away from it, the quantity of moisture will be all the greater. Exactly the same effect is

produced when the water from the roof is not absolutely cut off from the vertical walls of the building. In old buildings little or nothing was done to prevent this action except the drainage of the foundation. When the foundations were properly drained, and the stone used in them had a siliceous cement, the bad effect was exceedingly limited in extent, and did not usually show itself until after a long period of years. When, however, the stone was a limestone, or had a calcareous binding, this was slowly but surely dissolved out, the effect being all the more rapid as the locality was more densely populated. In order to prevent this action, the outside of the foundation walls against the earth is covered with asphalt, and what is called a damp course is frequently made by spreading a thin layer of asphalt over the horizontal surface of the wall above the ground so as to prevent the water from passing up into the walls of the building. If there is no protection from dampness, as in most old buildings, and the situation is a moist one, there is then another difficulty which hastens the decomposition of the stone, which is, that on the north side the stone is uniformly moist, while on the south it is, from its greater exposure to the sun, dry and moist alternately. As the moist side is already near its point of saturation it sheds the water, while that which is dry absorbs and then sheds it, carrying some soluble material with it.

When in sandstones the binding material is oxide of iron, there is frequently only just enough of it to hold the sandstone together, so that the least decomposition will cause the stone to disintegrate. Such stones as these, where there is a minimum quantity of binding material, are always rapidly decomposed when subjected to atmospheric influences.

Of the sandstones having a siliceous binding material, the Potsdam sandstone, which has been used in the recently constructed buildings of Columbia College, and the siliceous triassic sandstone which was the material used in the lower part of the Cathedral at Rodez, are the best examples; and in these no decomposition takes place. Of these sandstones it will be noticed that there are two general varieties, one in which the quartz grains are more or less large and are rounded, but are cemented together by silica, a variety which may be found in any quarry from which brownstone is taken, and is the only variety of that kind of sandstone which should ever be used for building. In the Potsdam sandstone, on the contrary, the grain of the quartz is quite small, its shape, when it can be distinguished at all with a magnifying glass, is always angular.

The stone is porous, but is cemented by silica, so that it appears, on a cursory examination, to be quartzite. This is the best of all building materials, though mouldings made of the other variety will last for many years, without suffering any appreciable amount of deterioration. The Potsdam sandstone has been but recently introduced into New York. It is an excellent building material. Almost the only objection to be made to it is that it is difficult to obtain it in large pieces.

The siliceous variety of the ordinary brown sandstone may be seen in any house where brownstone is used, in any large city. It has often been the case, that in examining houses where the decay has gone on to such a degree as to almost make it necessary to take the fronts down, certain of the stones that were composed either of pebbles, or of less coarse grains cemented by quartz, were still so sharp, having undergone no decomposition of any kind, that they could be put back into the building with perfect safety. This is true, not only of the facings of the building, but of the ornamental stone-work around the porticoes of the houses.   If the selection of only such stones as have a siliceous cement had been made from the quarry—as it undoubtedly was by the masons, who, at the time that the Cathedral of Rodez was built, were a religious order—we should probably have had little experience of the decay of sandstones. Those men selected from the quarries only such stone as they knew from tradition or their own experience was most suitable. It is a curious fact, and a standing monument to their knowledge, ability, skill and conscientious work, that many of the sandstone buildings which they constructed are still standing without serious decay, while those built later on, are either on the way to ruin, or are already in ruins.

All of the different kinds of weathering on the brown sandstone can be distinctly seen in Trinity and St. Paul's churchyards.   There is every gradation of it, from the stone that shows no trace of ever having been cut, and is just crumbling to sand, to that which stands apparently as fresh as the day it was put up.   That careful selection of the stone is all that is required to have it last, is shown by the fact that there is in Trinity churchyard a brownstone head-stone, cut on both sides, bearing the date of 1681, which still shows the marks of the tools used to cut it. It is but little pitted, though it shows the marks of age.   Others in St. Paul's churchyard just as sharp, and showing also the tool marks, bear the dates of 1760, 1766, 1770, 1781, 1787, 1793, while some of 1733,* and

* In St. Michael's churchyard, Charleston, S. C., there is a cypress-wood head-board, erected to the memory of Mary Anne Luten, who died in the year 1740, which is still in good preservation, and likely to last many years.

a little later, seem to have just started to crack, and many of later date
have crumbled to sand. All of these stones stand vertical. That to the
Rev. S. Johnston, President of Kings, now Columbia College, erected
in 1758 on the north side of the tower, was so defaced that it was recut
in 1883. The one to Mr. Faneuil, which lies flat on the north side of
the church, which was erected in 1719, has the inscription still sharp.
Most of those put up within this century have the dates barely visible.
One sharp stone, erected in Trinity churchyard on the south side of the
church, on Broadway, bears the date of 1746, and beside it is one of
limestone, bearing the date of 1793, the inscription on which will last
but a few years longer. Comparatively few of the stones erected after
the commencement of this century are well preserved.

The causes of the decay in all of these stones are the solution of the
binding material, and consequent deterioration of the strength of the
stone; or, where the stone is weak in some parts and strong in others,
as in the case of many of the ferruginous sandstones, the part of the stone
unable to bear the pressure yields, throwing the weight upon the rest of
the stone, which having too great a pressure upon it also yields, and the
stone fails entirely. Where the binding material is lime, the cause of the
disintegration is the action upon it of the minute quantity of carbonic
acid, and sulphurous and other gases, dissolved from the air in the rain
water, which readily attack the surface of the stone. If the mouldings
are improperly cut, so that the water remains on them for any length
of time, or passes through them, it may be that the surfaces of the under
sides of the projecting pieces, such as balconies or projecting sills,
which are improperly drained, and places where either the snow and
ice of winter or the water of ordinary showers may rest, so as to become
either absorbed in the stone or to pass directly through it, carrying with
them some of the binding material in solution, which eventually be-
comes entirely dissolved, will become either partially or wholly disin-
tegrated. Such is the case with the very thin mouldings which form
the tops of the windows of the highly-decorated houses built at the
time this sandstone was first introduced.

The effect of the small amounts of city gases absorbed by the water
in dissolving out the binding material of the stone, can be most dis-
tinctly seen wherever there has been a leak which has caused a perma-
nent drip over the surface of the stone. Here not only the change of
color, but the pitting from the solution can be most distinctly seen. It

is as true in nature on a large scale as in the laboratory, that the lime and magnesia is less soluble in concentrated solutions than in diluted ones. The amount of carbonic acid in the water and the air at any time is extremely small, but the accumulation of very minute quantities, acting over a large area for a considerable length of time, has, in many instances, been sufficient to dissolve out the whole of the binding material, leaving little else than a skeleton of sand. Where there are two binding materials, one of which is lime, the solution of the latter leaves the stone porous. When oxide of iron is the binding material, this is easily dissolved out, though not so easily as the carbonate of lime, unless the iron itself has come from the decomposition of pyrites, when it contains sulphur, in which case its oxidation would cause the solution of some of the binding material, which would also be acted on by the organic and mineral acids contained in the city gases. The decomposition of some of the sandstones of the coal formation in Kentucky is both interesting and peculiar. These rocks are of variable texture, being in places coarse and forming conglomerates, while in others they resemble a very uniformly fine sandstone. When this fine-grained rock is first exposed, it is quite hard. It stands up against the weather on all sides except the north. On this side it disintegrates and falls to sand, in irregular caves, often 10 or 15 feet high, forming by its disintegration the only pine lands of the district. This cave forming takes place horizontally and vertically at the same time, leaving a thin hanging front, which to all appearances from the outside is solid rock. After some time, holes of irregular size form in this front, which eventually breaks down, as does also the overhanging rock, when it can no longer bear the weight above it. In this case the disintegration is caused by weakness from the loose consolidation of the grains of sand.

The decomposition of the sandstones shows itself in several ways. The first and the most general one is by flaking, where large pieces, apparently parallel to the stratification, chip off, to the depth sometimes of a quarter of an inch. When these are examined carefully, they do not always show any trace of following the strata of the stone. This flaking does not take place until most of the binding material has gone, or been entirely dissolved out. Whether this material is of an organic or mineral nature, the depth of the decomposition will determine the point at which it flakes. The least blow, or a hard winter, or the infiltration of water which freezes, or the accidental arrangement of a series of mica plates,

will determine the point as well as the moment at which it will fall.
Sometimes, when this cause exists only to a small extent, or when there
is a cavity in the stone, it will begin to bulge away from the sides,
and may even crack out by the infiltration of moisture, when that mois-
ture is caught in the interior and freezes. This frequently takes place over
roughly finished surfaces, as the projecting fronts over doorways, which,
when the phenomenon commences, sound hollow when struck, and are
then entirely at the mercy of the frost, which will eventually break
them to pieces. I have frequently seen slabs on the upper parts of
stoops, five feet square, which were detached from the underlying
stone in this way, in the center of a larger slab, which remained
in this condition for several years, showing no trace of decompo-
sition on the surface, and which were finally detached from it either
by an accidental blow or by the heaving of the frost. When such slabs
are once broken or cracked, the pieces rapidly flake off. It is asserted
by some stonemasons that flaking may be produced by improperly dress-
ing the stone; that where the surface is dressed by the blows of heavy ham-
mers, particularly if a large number of blows are made in regular time by
a uniform movement either of machine or hand, the surface of the stone
becomes so fatigued that there is a tendency toward the separation of the
grains, and that a stone so dressed will eventually laminate. Whether
this be true or not, it would only account for a part of the difficulty.
Although this method of dressing has been very generally abandoned
for the planing and polishing machines, there is no diminution of the
lamination of these stones.

I have tried filling the cavities made by fracture out of a laminated
surface in such stones with stone putty or cement, but never have been
able to keep them from breaking off on horizontal surfaces. I have
sometimes been able to hold them in place for a few years with shellac on
a vertical surface. That the decomposition has gone beyond the pieces
flaked off may be seen by examining the surface of the stone from which
the flaking has taken place with a glass, even when the fresh fracture
has been exposed for but for a short time only. On looking carefully at
it, it will be found that the surface is pitted. This pitting on the outside
surface is generally taken for hammer marks, but on examining it care-
fully it will be seen that the stone has become open and that it has
changed color. This change of color is owing to the deposit of a certain
amount of soot at the bottom of each one of these holes, so that the

change is an apparent and not a real one. This pitting not unfrequently extends through the flake to the surface of the stone below. If examined carefully at this stage, it will be observed that the pitting is owing to the fact that the binding material has been dissolved out to a considerable extent. When such stones are examined with the mircroscope it will generally be found that the pitting, which is all that is at first visible, has been accompanied by a honeycombing of the stone, which appears as if riddled with minute holes when the pitting has gone deep enough, and that the binding material, of whatever nature it might have been, has been either partly or wholly removed. This is especially true when it is carbonate of lime, or when there has been any cause of weakness, such as the presence of minerals which have a tendency to assume specific directions. Any cause which will produce an unequal expansion, such as the freezing of the water infiltrated, or the exposure of the surface to a very hot sun, will have a tendency to cause the stone to break off in thin lamellæ, or to flake. Pitting as it usually occurs in the brownstone of the city, cannot generally be seen by the eye, and can only be observed by a careful examination with a glass. Occasionally a thin flake of the decomposed stone is sufficiently honeycombed to allow the light to pass through the fine pin-holes. Sometimes, however, as in the stone of Castle William, on Governor's Island, it is quite deep, in some cases in rounded, but oftener in elongated holes, which have penetrated the stone a quarter of an inch or more. When the pittings are so large as this the stone does not flake, but falls into sand.

Sometimes the stones do not flake, but simply crumble over the surface and at the sharp edges. This occurs where either the angles have been too sharp for the stone, or where the stone has not been properly undercut, so that the water passing through dissolves out the binding material and leaves nothing to hold it together. This kind of decomposition takes place in the quarry as well as in the structure, and may have taken place to such an extent that the stone is worthless to a very considerable depth. I have known of some cases when it was necessary to strip the sandstone of a quarry for 20 feet before arriving at any sound stone. It is said that in opening new sandstone quarries the rock for 2 to 3 feet can be removed with a pick, and that it is generally necessary to reject the stone for several feet. It is, therefore, not safe to use a stone from a new quarry without first making a complete microscopic examination of it, which should be supplemented by a

partially chemical one, to ascertain first whether the stone is sound; secondly, whether it contains any material which will be likely to be either decomposed or be absorbed by the action of the elements. With the sandstones that are very porous and have lain in the quarry bed, the mere freezing of the water absorbed will be sufficient to flake off part of the surface; or, when that does not take place, to crumble the stone considerably.

It was formerly the practice to require by contract that the stone should be exposed to the air for a certain time after being taken from the quarry to season; that is, have the quarry water dried out of it, and to ascertain whether there was any commencement of decomposition or disintegration in any part of the stone. This was the practice of most of the ancient architects. Sir Christopher Wren required that the stone for St. Paul's Cathedral, in London, should season for two years after it was taken from the quarry before it was put into the building. It is well known that stones with the quarry water in them are much softer than after exposure. This is particularly true of the soft limestones of Paris, which can be easily cut with chisel and saw and planed with a plane while the quarry water is in them, but which afterwards become quite hard, so as to very considerably increase the expense of dressing them. It has been frequently remarked that when stones with the quarry water in them are exposed to the temperature at which the water freezes, they chip much more readily than when, after it has once been dried out, they are exposed to moisture. The explanation which has been given for this is that the quarry water contains salts in solution, which, on the evaporation of the water, bind the stone together, and thus make it stronger. Whether this is so or not, it was well known to the ancients, and it has been shown by modern experience that a tempered stone lasts longer than a fresh one, and the fact merits the attention of builders. It often happens that decomposition may have gone on in certain localities to the depth of three to four inches without its being perceptible on the surface. Where iron pyrites, in any shape in which it can decompose, is present, this will act upon the various kinds of binding material, and cause the stone to disintegrate.

The causes of decay then are: first, improper selection of the stones in the quarry; almost every sandstone quarry contains poor stone, as well as that which will last for a great length of time, and this can always be dis-

tinguished because it is highly siliceous, and contains no traces of mica, and but little material soluble in acids. The presence of mica is essentially bad because it shows a probable tendency to lamination in the stone. Where the stone would otherwise be good, the improper cutting of mouldings, and especially the want of undercutting of projecting mouldings, so that the water will be shed instead of running up over or down through, is the most fruitful cause of decomposition in the buildings of the present day. Where the edges are very sharp, there will always be a tendency, by capillary attraction, for the water to run up until it meets some point so ascending that it cannot follow up, and from here it will drip without passing through the stone. Where the surfaces are flat, crumbling or lamination will take place; where they are thin, so that the water will pass through them, the stones will crumble and flake; and where there are large surfaces immediately under projecting mouldings, in such a condition that the water will flow up over the moulding, and then slowly down the face, lamination will take place. It is a remarkable fact, in looking over buildings that have undergone this decomposition, that the greater part of it will be found within a comparatively short distance from the ground—generally within ten feet. From this point it gradually diminishes up to about 50 feet, where it ceases entirely, unless there is some action of sulphurous gases, or the acid or alkaline gases from the combustion of wood or coal, or from manufactories, coming in contact with the stone. In all the buildings that I have had occasion to examine, beyond one hundred feet there is not only no decomposition, but the stone is harder than it appears to have been originally. The same stone which would last almost indefinitely when put into a building in the open country, with no other buildings near it, would be subject to decay in the city. The present mania for high buildings, if it had not been stopped by law, would have increased this decomposition, and would have greatly raised the maximum height to which it would reach.

The stone of which Trinity Church is built is a red sandstone, which has always been supposed to be homogeneous, and, until the decay which has become manifest within a few years, has always been supposed to be one of the stones that would resist the action of the weather. The investigation which has been made,* has shown not only that there are different

* The microscopic examination of the specimens taken from Trinity Church was made by Dr. A. A. Julien, of the School of Mines.

kinds of stone used in the building, but that none of the varieties are, strictly speaking, homogeneous; for, instead of being composed entirely of quartz grains, united by a cement, they contain not less than twenty-eight different varieties of minerals, embracing twenty-five species, some of which are quite susceptible of decomposition, and many of which have begun to decay in places, and this process is still going on. The following is the list of the minerals found in the sandstone of Trinity Church :

Quartz,	Biotite,	Calcite,
Amphibole,	Hydro-biotite,	Dolomite,
Epidote,	Sericite,	Magnetite,
Garnet,	Margarodite,	Hematite,
Oligoclase,	Fibrolite,	Limonite,
Orthoclase,	Brown tourmaline,	Göthite,
Microcline,	Green tourmaline,	Pyrolusite,
Kaolin,	Indicolite,	Rutile,
Muscovite,	Cyanite,	Asphalt.
	Apatite.	

In addition to these, there is a considerable quantity of opacite, a name given by Vogelsang to the black opaque grains and scales which so frequently occur in rocks, and which cannot be identified with magnetite, menaccanite or any other mineral. What is more remarkable in this enumeration of species is the complete absence of pyrites. All of this stone contains a considerable quantity of material easily soluble in acids, most of it effervescing, a certain portion of it going into solution with the greatest ease. If the stone had been properly selected at the time of the building of the church, or if the mouldings had been so constructed as to shed water, I think there would have been but little decomposition at this time, but without some protection it must eventually have taken place.

The depth and kind of decomposition differ in each variety of stone, but all have undergone more or less of it, and wherever any of the stone lies below a projecting piece, the decomposition has gone on to a very considerable extent. After selecting the pieces that were more or less affected, I succeeded in getting a piece of the stone which had been lying exposed to the weather until within four or five years, and had then been accidentally buried. I had it dug up and left exposed to the

air for some time, and then carried to the cellar of the church, where it was dried at a temperature of about 60 degrees for two or three months before the specimens for examination were taken from it.

The decomposition shows itself in these stones in three different ways : first, by deep pitting and falling out of grains of the minerals which compose the stone; second, by lamination; and third, by crumbling to powder. The way in which each one of these is effected depends upon the position of the stone. The pitting is quite irregular, and is due to the removal of the cementing material from the surface; and where this has been done by the action of the weather, there seems to have been a deposit of sooty material at the bottom of the depression which has slightly changed the color of the stone, so that the outside is of a different tint from the inside. The cause of this is not shown until the stone is examined with a microscope of high power. On treating such a stone as this with acid, generally no effervescence takes place, and very little of it is soluble. The same is true, but to a less extent, where the rock has flaked. The flaking does not appear to be owing to the fact that the stone has been used in a different position from that which it held in its quarry-bed, though in many places it has evidently not been placed in its natural position; nor to the fact that the stone is laminated, owing to the presence of large quantities of mica; but it is owing to the absorption of the cementing material by atmospheric influence. It is also to be observed that there are in many sandstones which are used for building in this city, organic materials which act as the cement, and are easily decomposed by exposure to the weather. Stone of this kind, except to a very limited extent, does not seem to have been used in the walls of Trinity Church, though it is extremely common in other parts of the city. It can only be kept from complete disintegration by filling the pos of the stone with some substance which will prevent further encroachments of the weather, which must be renewed from time to time as it is decomposed or dissolved out. By the original agreement, the stone of which the church was built was to be taken from a single quarry, which had been determined by observation to give a strong stone, but this agreement, like that made for the stone of the House of Commons, in London, was not adhered to. The different varieties of stone used in the building are:

First.—Fine-grained, lamellar reddish-gray. Of this variety there were 15 specimens.

Second.—Fine-grained reddish-brown. Of this variety there were 6 specimens.

Third.—Fine-grained light gray. Of this variety there were 6 specimens.

Fourth.—Coarse yellowish-gray. Of this variety there were 3 specimens.

While the varieties examined were most of them weathered, specimens of these varieties are easily distinguishable in the unaltered stones of the building itself. The stone was, for the most part, of the same origin, having had in the quarry a calcareous cement. It does not appear that any large quantity of this stone would have endured exposure in the quarry or in the building for any great number of years without being affected. None of those which had a siliceous cement appear to have been decomposed. There are two types of the first variety of stone, distinguished as A and B. Both of these were taken from the piece that had not been exposed in the building. The type A was coarsely laminated and contained the following minerals: Quartz in very irregular grains, most of them rounded, some of them quite spherical, filled with minute bubbles either in motion or quiet, varying in color from smoky, through white to red; orthoclase, plagioclase, probably oligoclase, and microcline distinctly cleavable. These were the prevalent minerals. Magnetite and menaccanite in grains of varying size are quite evenly distributed. Biotite, hydro-biotite, muscovite and margarodite are quite regularly scattered through the rock; epidote in small particles, rarely in prisms; green and blue tourmaline in occasional grains; iron ochre and garnet in very small grains, and sericite in minute bunches around and between the grains of quartz and feldspar, are also found. Of all the minerals the micas are those which have undergone the most decomposition, the hydrated varieties appearing everywhere, and these frequently having become opaque from still further decay. The rock gave a lively effervescence with citric acid, showing the presence of calcite; apatite was also present in small quantities.

The composition was determined as

Quartz	57 parts.
Feldspar	31 "
Fine-grained minerals	12 "
	100

The rock was slightly altered, as were also the minerals that compose it. To give a fair idea of the amount of decomposition, the grains of about the same size were counted and classified according as they were more or less affected.

	Clear.	Slightly Cloudy.	Very Cloudy or Opaque.
Orthoclase	6	22	16
Oligoclase	4	1	
Microcline	1		
Hydro-biotite	14	14	12

It thus appears that the feldspars were the most decomposed.

The second variety of the stone, B, which had not been put into the building, had lain on the ground in the churchyard exposed to the elements for about 30 years. One part had been acted on by the weather, and was of lighter color than the rest, owing to pitting. Here the dropping out of grains of quartz and feldspar is distinctly visible, but all parts of the stone effervesced with citric acid. The specimen contained about the same quantity of quartz and feldspar as No. 1. Hydro-biotite, sericite, margarodite and amphibole are in elongated and crushed fragments; kyanite, blue tourmaline, hematite, magnetite, limonite and calcite were also found.

The way the alteration of the minerals which compose the rock had taken place, is given below:

	Clear.	Cloudy.	Very Cloudy.
Orthoclase	9	22	4
Oligoclase	11	2	
Microcline	1	1	
Hydro-biotite	3	1	2

The weathered part of this variety is deeply pitted, but there does not appear to be any appreciable widening of the distances between the grains, but the rock is honeycombed by the deeper of the pits going through the flaking; the calcite was entirely gone, no effervescence taking place in citric acid. The minerals themselves do not seem to have undergone any decomposition since they became incorporated in the stone.

Of the second variety there were two unaltered specimens, both of which were taken from the inside of the tower high up in the steeple. It contains much more ochre than the other varieties. The minerals

composing it are quartz and feldspar as before, brown tourmaline, sericite, margarodite, hydro-biotite, garnet, epidote and magnetite. It does not effervesce.

The proportion of the ingredients contained in the stone was:

Quartz 41
Feldspar 35
Cement... 24

All the crusts are deeply pitted and honeycombed.

The third variety is fine-grained and indistinctly lamellar. The fresh specimen was taken high up from the inside of the tower. It effervesces rapidly with citric acid. The most prominent mineral is quartz, which is quite clear; the orthoclase is generally cloudy. The accompanying minerals are amphibole, garnet, margarodite, hydro-biotite, brown tourmaline and sericite. There is but little plagioclase. The following proportions of these minerals were found in three specimens:

	1.	2.	3.
Quartz	53	61	51
Orthoclase	22	17	39.5
Hydro-biotite	..	2	0.5
Cement	25	20	8.5
	100	100	99.5

The feldspar is whitish, the cloudiness being caused by a great abundance of microlites generally arranged in parallel planes about normal to the direction of easiest cleavage of the feldspar. Between these cleavages there is a slight transparent film of sericite which polarizes feebly. This mineral is probably the result of the commencement of the alteration of the feldspar, but in some of the grains the decomposition has not progressed further, while in others its progress is shown by the innumerable very small microlites which are quite colorless, but give a milky appearance to the grains where they occur. They are probably both sericite and epidote. The hydro-biotite is transparent green in the center, and opaque brown on the edges, showing a commencement of decomposition. The other minerals, margarodite, sericite, epidote, tourmaline, iron ochre, do not show anything peculiar. Where the specimen is not decomposed it is close-grained without interstices, when it is weathered it is honeycombed.

The fourth variety was coarse-grained yellowish. It is quite compact, so that little pitting is found on it. It contains no carbonate of lime. The quartz is in closely-packed grains, generally clear, but containing some inclusions. The grains are angular. The orthoclase is also angular, some of the grains being cloudy. The plagioclase is also angular, and polarizes the light strongly. The biotite and hydro-biotite are in yellowish-green scales. The other minerals are margarodite, epidote, amphibole, sericite, magnetite and iron ochre. No pitting occurs, except in the specimens in which there are red flakes, and here it is quite deep. The specimens where this occurs were taken from the outside of the church near the ground, where they were exposed not only to the action of the weather, but to that of the dampness coming from the ground as well. The composition of these specimens is given below :

	1.	2.	3.	Average.
Quartz	40	70	57	56
Orthoclase.....	53	18	31	34
Cement	7	12	12	10

With regard to all of the stones, it may be said that the disintegration is not caused by either the looseness of aggregation of the particles, nor by the structure of the stone. In all the specimens there was shown great compactness and no cavities, except occasionally when grains had fallen out owing to the absorption of the binding material. It was not influenced by structure, for while there is an abundance of mica, the splitting is as much across the mica plane as in it. If anything, the mica, though acted on, seems to have played, to some extent, the part of a binding material.

The disintegration is not owing to the decomposition of the feldspar, most of which belongs to the variety orthoclase, which decomposes with comparative ease. It is to be noticed that the average amount of orthoclase in the specimens examined was between 29 and 30 per cent. Most of these grains were more or less decomposed, but there was no evidence to show that the decomposition has progressed to any extent since the consolidation of the sand into stone. On the contrary, it seems to have been completely arrested. This is shown by the fact, that in the most highly-weathered specimens, the proportion of milky grains of feldspar showing inclusions and the commencement of decomposition is no greater, and the decomposition no further advanced than in the

fresh ones. The stone seems to have been formed out of the destruction of granitic rocks, which had commenced to decompose during the trias previous to their destruction, and to have been consolidated under immense pressure, as is shown by the crumpled and irregularly broken and curved mica plates, and the compact nature and close union of the grains.

It appears, however, that some decomposition has actually taken place in the minerals of the stone since its consolidation into rock form. This is shown in the condition of the iron micas, both the biotite and hydro-biotite, which contains from 5 to 25 per cent. of ferrous oxide, from 1 to 4 per cent of water, which readily decompose. That some decomposition has taken place in it is shown by the varying color of the mineral, individual pieces being mottled brown and green, and also by the action of polarized light upon them, as well as by the fact that their passage into chlorite and iron ochre can be distinctly seen. Part of this decomposition is seen in the unaltered stones, but it is much more prominent in the weathered ones, and while of itself it would have had but little influence in weakening the stone, it undoubtedly put the constituents into a form in which they would be more easily attacked. A very slight alteration in the margarodite, amphibole and garnet is seen. While this decomposition is not sufficient to account for the entire weathering of the stone, it undoubtedly contributed, although slightly, to it, as at the most it could weaken the stone but little. It is, however, to be observed that the mineral calcite is present in every one of the unaltered specimens except the last variety, which consisted of three specimens out of the thirty examined, and that in all the weathered varieties this was either wanting entirely or present in very small quantities, and that wherever it was dissolved out to a small extent, there the stone was pitted, and when entirely gone, honeycombed, rendering that part of the stone porous and open on the outside. How far the iron has been removed at the same time as the lime, cannot be stated. There has been no very great change in the color of the stone—certainly not sufficient for us to suppose the removal of any large quantity of iron oxide, and but little that may not be accounted for by the presence of small quantities of carbon deposited at the bottom of the pittings in the stone. The decay is deep-seated, penetrating, at times, several inches into the stone, which still looks sound on the outside, not showing the least trace of flaking; but in no case is the lime

entirely wanting from the interior of the stone, even when it has been
entirely dissolved from the surface.   The removal of even a very small
quantity of lime would render the ochreous material which is so abund-
ant much less stable, and far more likely to be acted on.   It is not very
homogeneous in any part of the stone, but is much less so where the
calcite is gone.   This action on the iron, while it could not go on at any
great depth from the surface, and so could not weaken the stone much
in the interior, was at its maximum on the outside of the stone; and, as
it was already porous from the solution of part of its binding material,
this rendered it likely to flake at short distances from the surface, the
stone falling off in layers along the lines of least resistance, correspond-
ing to the plane which included the greatest number of pit bottoms,
and consequently give an appearance of lamination in the stone which
did not exist in the stone itself.   Frost would separate such stone into
lamellæ very rapidly.

Independent of all these considerations, is the fact that there is in all
these stones a certain amount of organic matter, which can easily be
detected on heating the stone by the empyreumatic odor which it gives
out.   The microscope does not show any vegetable matter, nor, in most
of the stone, any traces of carbon which is not in a state of combination.
It is well known that organic acids form combinations with bases, which
combinations are decomposed when submitted to the continued action
of moisture, and will be all the more rapid as this moisture is slightly
acid, as it is in all cities.   It is most common to find, either in or in the
vicinity of these rocks, large quantities of organic materials, either fos-
silized, such as plants, lignite, coal, asphalt, or combined with bases.
Asphalt was actually found, in very small quantities, in two specimens
of undecomposed stone.   In other sandstones organic acids have been
found.   It is more than probable that they would be found much oftener
if looked for.   The expense of such investigations, however, generally
prevents their being made.   Dr. Julian has called attention to the fact
that the ochreous condition of sandstones of different geological ages is
not the same.   In those of the paleozoic periods it is hematite, which
frequently produces such a permanent cement as to make a durable
building-stone.   In the tertiary it is turgite or limonite, and in so small
quantity as to produce in many cases only sand rocks.   I once had occa-
sion, in the Far West, to examine the abutments of a railroad bridge
built of stone excavated in the winter from such a quarry, and

found that the rock, though apparently strong, could be rubbed into sand with the fingers. In the sandstones of intermediate geological ages, göthite predominates, and is in variable quantities in different layers of the same bed, making the rock correspondingly strong or weak. The range of the variation is so great as to imply the possible association of organic acids with the iron oxide. Whatever may be the cause of the decay, it is not loose consolidation of the rock. It is not wholly explained by the solution of the calcareous matter, but is undoubtedly hastened by it. It had progressed somewhat in the quarry before the stone was put into the church, and is still going on. The flaking of the stone in thin parallel layers is perfectly explained by the solution of the lime, but the deep-seated decay needs further study, as the action of the acid, waters and gases does not fully explain it. The flaking is hastened by the heat of summer and the frost of winter, and is always most prominent where there is any drip of water.

It is certain that the decay can be retarded, even in the buildings which were constructed twenty or thirty years ago, so as to make them last for many years. It is not certain that it can be completely arrested. The decay in Trinity Church is one of the best examples that could have been chosen, for it applies to one of the most compact and well-selected building stones of the country, which was selected at the time on account of its supposed great durability. It is certain that from the same quarry, by a careful selection of stones with siliceous binding materials, and the rejection of all others, material might have been selected that would have lasted indefinitely.

It has been usual to consider all sandstones as good for building purposes, or not, according as they were compact or more or less porous, and this rule has undoubtedly influenced the choice of the stone which has been used, which is in this respect an extremely good one. The theory generally accepted is that the porous stones absorb moisture, which in the cold of winter freezes and, expanding, disintegrates the stone; and that the heat of the sun also contributes its share to the expansion, which causes the flaking. This cannot be said to be true to any great extent of the stone of Trinity Church, except where the moisture, from the defective cutting of the mouldings, has not been shed from the surface, and has been constantly dripping on the stones below. It is specially observable that on all the faces of the building underneath projecting stone, whether it has had mouldings cut on it or not, the stone

has decomposed more or less.   It is a remarkable fact that in all of the specimens taken from all parts of the church, both inside and out, and representing so many varieties of stone, no iron pyrites has been found, and consequently no such cause of disintegration as often produces decay in other building materials can be ascribed to it.

The microscopic examination revealed the fact that a considerable quantity of carbonate of lime was contained in most of the specimens, the fresh stone containing the most; and that in all the decayed crusts the lime was present in very small quantities only, or not at all; and in many cases this decomposition has gone on to some extent, even to the depth of eight or ten inches in the interior of the stone, without showing any trace of decomposition on the outside.   The stone was thus rendered extremely porous by this solution, even where the weathered exterior retained the smooth surface of the original dressing.   It therefore was porous in the interior as well on the surface, and was subject to decomposition in all its parts.   This is shown to take place far into the interior, even when it appeared not to be affected on the outside at all. I was not able to find a single specimen of the stone in any part of the building that had not apparently undergone this action to a certain extent.   In some few cases the pitting is owing to the dissolving out of a small amount of the oxide of iron, which serves the purpose of an additional cement; but it is generally the carbonate of lime which has been removed.

In every case—and but few such were noticed—where the stone has been set upon its edge, the lamination has gone on to a considerable extent; but, what is more remarkable than this, is the fact that all of this stone in every part has undergone more or less of this interior decay, which seems to extend through the whole stone, and in some places where it was particularly weak has caused the bulging of the face in thin laminæ, even where the stone has been laid in its quarry-bed.   In a very few instances it seems that this bulging may have been owing to a decomposition of some of the minerals contained in the stone.

None of the causes which are usually alleged to account for decay seem to be prevalent here.   These are usually a loose consolidation of the sand of the stone, owing to the fact that the cementing material is not quartz, as it is in the Potsdam sandstone used in the new buildings of Columbia College, but is some material subject to decomposition.   The true cause of the decay seems to be the fact that, owing to the defect

of the undercutting of the mouldings where there is a drip, the water remains in and is absorbed by the stone, and in some cases passes through it. Every shower of rain, particularly in cities, removes a very minute amount of binding material from the outside. When the stone is soft, owing to the small quantity of binding material contained in it, the action is comparatively rapid; and if to natural causes are added the corrosive gases of the city, decay will be very rapid. This decomposition goes on most rapidly under projecting horizontal pieces. The flow of rain water over a vertical surface of stone injures it but slightly, only that which is absorbed affecting any damage. The rest is so rapidly shed that it has no time to dissolve out anything. When the water is rapidly shed, the solution of the binding material is uniformly slight, as the evaporation of the water leaves all the solid parts which it may have dissolved, behind. But when the water passes through the stone, or the quantity dripping on it is such that the stone cannot absorb it, so that it either passes directly through or runs off from the surface in more or a less of a stream, then the quantity actually dissolved out will always be a maximum. It is to be remarked that the places where decay exists are precisely in these conditions. In the country this would probably have but little effect, and the building would last a long time; but in the city air, which is charged with a larger quantity of carbonic acid than is usual in country air, and also with small quantities of sulphurous and sulphuric acids, and with all the acid gases that result from the decomposition of city refuse, which are absorbed by the water, it has the power of dissolving the cement of the stone even though in minute quantities, and, after a considerable period, renders the stone so loose that after a time it will flake and fall to powder, or become disfigured. As soon as this state of things was suspected, a careful chemical examination was made of five of the stones of the church taken at random, selecting however one, No. 1, which was fresh stone.

The analyses of these stones is given below. They show that in the weathered specimen a large quantity of the binding material has been dissolved out, leaving the stone in a condition to be acted upon by all the decomposing agencies of the weather, as frost, expansion from heat, expansion from cold, and the tendency which decay always has to spread when it has once begun.

	No. 1.*	No. 2.	No. 7.	No. 10.	No. 21.
	Fresh unexposed stone.	Weathered, Outside of No. 1.	North side tower base and buttresses.	South side between 6th and 7th buttresses.	South side base between 4th and 5th buttresses
	Interior.		Scales.*	Scales.	Scales.
Insoluble.......	90.30	91.64	96.09	95.82	94.27
		Soluble.			
Iron oxide......	2.25	2.66	2.32	2.39	1.97
Lime...........	3.61	2.45	0.26	0.14	1.51
Magnesia.......	0.30	0.36	0.28	0.27	0.20
Carbonic acid, organic matter, etc...........	3.54	2.89	1.05	1.38	2.05

In all of these stones there is a small amount of organic matter which gives a peculiar smell when burned. In many of them no trace of effervescence with acetic acid could be seen under the microscope, and after careful drying in an air bath the total amount of soluble material did not exceed three per cent.

The examination shows that there is no cause of decomposition in the stone itself; that the decomposition has gone on in all parts where the stone has been exposed to the air, whether inside or outside, with regularity; that most of the stone in the interior, or at a certain distance removed from the surface, is in about the same condition in which it was in the quarry; that the mere action of moisture, or of the air, affects the stone very slightly when there is only a vertical wall to be acted on. The decay of the stone is, therefore, owing to causes which act from the outside entirely, and it remains now to consider what will be the best method of adding something from the outside of the church which will prevent further attack upon and consequent decomposition of the stone. This is a matter of great importance, for, until the flaking of the stone, it was always supposed that the stone of this church would not decompose. The greatest care was thought to have been taken in its selection, but the investigation shows that the solution of the ingredients of the stone of one of the best buildings of the country, from the outside, has gone on to such an extent as to cause the stone to decay very perceptibly in

* These analyses were made by J. B. Mackintosh, E. M., of the School of Mines.

less than forty years.* I am glad to be able to call attention to the prob-
able solution of the problem, which, if not soon solved, will make most
of the handsome edifices of New York ruins in the course of a few
years.

The methods for the preservation of stone are, first, properly in-
clined surfaces that will shed the water so that it cannot stand on the
surface; properly undercut mouldings, so that the water cannot creep up
under and remain so long as to dissolve out the binding material; keep-
ing out the water as far as practicable. This must be done by water-
proofing, so to speak, the foundations: placing a thin layer of asphalt
between the foundation stones and the vertical walls of the building
proper, 2 or 3 feet above the ground. This would prevent the slightly
acid waters from the earth rising and decomposing the lower tiers of
stones. Asphalting the fronts of the foundation walls themselves,
previous to throwing the earth back against them, would prevent the
entrance of a considerable amount of water, so that if the face of the
foundation next the soil and its top were asphalted, the water would not
enter here.

If the stone has been already acted on, and is to be preserved, some-
thing must be added to the outside to fill up the pores formed by the
solution of the binding material, and prevent further encroachment of
the water containing the acid gases in solution. To heat the surface of
the stone, already weakened by decay, is only to make the decomposed
surface more liable to flake. It must, therefore, be applied to the cold
stone. Anything that forms a gum that is impervious to water, and can
be made sufficiently liquid to penetrate the pores and pittings of the
stone, will answer the purpose. Bees-wax or rosin dissolved in any of
their solvents, with or without oil, have been used. Boiled linseed oil,
which forms a gum, does very well, and only slightly discolors the stone
for a time. But all of these substances decompose after a few years,
and must be renewed. Paraffin dissolved in boiled oil, and put on hot,
answers better, as it is more effectual, and after one or two applications
will fill the pores completely. But no substance applied after decay has
begun is equal to a preventive, and no preventive can preserve flat
surfaces and projecting mouldings which are not undercut, from decay.
Water-glass associated with a bituminous substance, a preparation
known as Szerelmy's compound, was used on some of the interior

* All the decayed surfaces of the stone of Trinity Church were recut in the summer of 1884.

courts of the Houses of Parliament some years ago.   I inspected all of these courts in the summer of 1884.   The dilapidated condition not only of the finials, but even of the flat surfaces of the stone, showed that it had not even been a palliative.

About the year 1868, the Vielle Montagne Co., of Liege, introduced the process of painting with water-glass and oxide of zinc. This was applied to the railroad station at Liege, and to parts of the Houses of Parliament. A silicate of zinc and lime is thus formed on the outside of the stone, which indurates it superficially. The want of penetration, or careless application of the material, makes the surface flake, and it, like all other paints, requires frequent repetition.

Ransome's process, which consists of using water glass, with a subsequent application of some chloride, answers very well, but is a very expensive process, as it requires that the stone should be entirely refaced, in order to clean it. This, and the number of applications of the silicate, and subsequent application of the chloride, consumes so much time, and is so expensive, that it cannot come into general use. It has been applied satisfactorily to some small parts of the Houses of Parliament, but has been discontinued on account of its very great cost. The same is true of a number of other processes, which require first, the cleaning of the stone, and the subsequent application of several chemical substances, such, for instance, as the process of the Silicate Paint Co.   They are excellent in themselves; they can be put on with certainty, when used with great care, and over small surfaces; but when they are to be applied to buildings already constructed, they either fail from the impossibility of applying them evenly on large surfaces, or become entirely impracticable on account of the expense.   The principle of most of these processes is correct, and it is to be hoped that some corporation will find it to their advantage to have investigations made that will lead to the discovery of some substance which is both cheap and of easy application.   Such substances undoubtedly exist, but they require to be sought for. Any process which requires the formation of a chemical union between the stone and the substance applied, must be put on in such a way as both to be certain of its penetration, so that the action will not be superficial, and to insure that the compound formed will not only become sufficiently indurated to withstand the weather, but sufficiently compact not only to resist the penetration of gas, but also to prevent the absorption of moisture, and to shed it at once from its surface.

Very few natural stones even do this, and they are the very compact siliceous stones, or dense carbonates, which are very homogeneous.

When oils, with or without paraffine and sulphur, are used for water-proofing stone, they should always be applied while hot, as they are then much more liquid, and, consequently, more effectual.   It is better also that the application should be made when the stone is also warmed by the heat of the sun—that is, either in the spring, summer or fall, rather than in the winter. This application of oil, however is not permanent in its effects. The oil forms a gum in the pores of the stone, filling them up temporarily, so that the water does not enter, but after a time this decomposes, and must be replaced. It is very easy to distinguish the surfaces of stones that have been treated with oil, by observing them immediately after a shower, when it will be seen that the stone becomes dry much more rapidly than that which has had no such application. The necessity of applying the oil once in every two or three years is one reason why it is so little used. When paint is used, the solid material with the oil is of no account whatever. It remains on the outside, and does not enter the pores of the stone, and when the gum is decomposed it is washed off the surface. Another objection to painting the stone is, that while adding considerably to the expense of the process for protecting the stone, it adds nothing whatever to the efficiency of the oil, and it is very apt to fill up the fine tracery that may be upon the surface of the stone. It is, therefore, entirely unnecessary, and in some cases may be injurious, as preventing the penetration of the material which is designed to water-proof the stone. When oil is heated with an excess of sulphur it dissolves about 13 per cent. of it. More of it will dissolve in hot oil, but the sulphur crystallizes out upon cooling, and when there is a large excess of it, a partial decomposition takes place, and sulphureted hydrogen is formed. The oil, with the proper amount of sulphur, becomes thick and dark like molasses, but when heated is quite thin. When the stone is coated with this material it penetrates below the surface, and as the sulphur is simply in solution, when the gum of the oil decomposes it leaves the sulphur still in the pores. Two or three applications of such a material as this would prevent any further decomposition. It has been found by experiments made on the Houses of Parliament that sulphur applied in some such way has been the only thing that has arrested decomposition in that soft, porous stone; but even this preparation has not prevented the flaking of

the surface of the stone after an exposure of about twenty years, prob-
ably because it was not applied hot, and was put on when the stone was
moist, or when the weather was cold.

If 20 per cent. of paraffine be added to oil containing the sulphur
in solution, it thickens when cold into a semi-solid buttery mass, but is
fluid when hot. Such a preparation as this, applied hot to the stone,
gives another element with the sulphur, which does not decompose, to
fill the pores of the stone. There may be cases in which it is undesira-
ble and inconvenient to use sulphur, and in these cases 20 per cent. of
paraffine mixed with hot oil may be used. The same is true of this
as of the other preparation mentioned. The paraffine, which is, like the
sulphur, practically indestructible, remains in the pores of the stone
after the decomposition of the organic matter of the oil has taken place,
and one or two coatings of such material as this will waterproof the stone
entirely and prevent further disintegration. Other preparations of paraf-
fine may be used to advantage, but those which involve heating the surface
of the stone should be avoided. It has been suggested that these prepara-
tions discolor the stone. It is true that the color of the stone is darken-
ed by them, but the stone is not disfigured, as the color given is very
nearly uniform over the whole surface. In some cases the stones, after
the application of the oil, have been washed with ammonia salts to take
off the excess of the material from the surface. It is generally, how-
ever, undesirable to do anything to the stone after the liquid has been
applied, as the surface will very soon become bleached by the action of
the weather.

It has been objected to the use of oils that they would interfere with
the adhesion of the mortar in the stone, if the stone were treated before
it was put into the building. In actual practice, however, this does not
seem to be the case. The stone is not only more thoroughly protected
from moisture upon all sides, for in stone buildings in damp countries
the moisture is as much to be feared on the inside as on the outside, but it
does not seem in any way to deleteriously affect the binding power of the
mortar. It acts advantageously both on the stone and the mortar, and does
not influence any of the chemical changes that take place, either by ac-
celerating, retarding or preventing them. This fact was well known to the
ancients, for they used oil in mortars and cements to a considerable ex-
tent. When it is desirable to use soft and very porous stones for build-
ing purposes, the stone should be dipped either into boiling oil or some

such preparation as this, before being put into the building, so that its entire surface may be coated. The experience of the last thirty years shows that the stone cannot be perfectly protected unless this is done on all sides of the stone. Such coating does not in any way prevent the adhesion of the mortar if done either before or after it is put into the building.

In the experiments made in the year 1861, I was successful in preventing the further decay of a building which has, up to this time, shown no sign of lamination or disintegration. This was done by the use of thoroughly boiled oil alone, applied with a brush during the warmest of our summer weather, when the stone was very hot. It was done twice at intervals of several years, and completely arrested the decay for the time being. It would have been much more effectual if the preparations mentioned above had been used. The application of such material does not change the surface of the stone. It was used almost exclusively to porous sandstones. It seems to form a sort of cement, similar to the organic binding material which is so common in many of the brown sandstones, but with the limestones this has not been found useful to any extent. It requires renewal so often, and changes the color of the stone so unpleasantly, that it has not been found of service with these stones. Such preparations are, however, of no use on stones of whatever character, where the decay has been produced by disintegration caused by the unequal expansion and contraction of the minerals forming the stone. Such disintegration is very slow in most stones. It has taken thousands of years to produce it in the granites of the obelisks of hot countries. It appears to be more rapid in cold ones; but it takes place with unerring certainty and regularity in all those rocks where the minerals composing them have different rates of expansion and contraction. Here, as in the other case, there are cavities, but the filling of them does not arrest the decay, because it does not attack the cause. Nothing will arrest such decay, and no other decay in stone, except those caused by the air and water can be prevented by any application to its outside. It is therefore useless to attempt the preservation of such rocks as granite, since the unequal expansion of the minerals which compose the rock cannot be arrested by filling the cracks. They are applicable only to stones from which something has been dissolved out, leaving cavities which can be filled from the outside. Water-proofing the surface of a stone has the effect of keeping the water

out of pores that allow some of the constituents of the stone to be at-
tacked, and is effectual in those stones only which are either porous by
nature, or have become so by the solution of parts of their ingredients;
but it has absolutely no effect where there is any movement in the parti-
cles which compose the stone, however this movement may be produced.

No method of protecting the surface of the stone of the Houses of
Parliament has, so far, been successful, except where sulphur was dis-
solved and added to the outside of the stone, and this rendered the stone
for a very long time water-proof.   It had remained so for twenty years
up to August, 1884, when I examined it, and found that it had begun to
laminate, the part of the stone containing the sulphur peeling off in thin
scales.   The experience of the repairs at the House of Commons is that
most of the substances which are supposed to be useful, are absolutely
useless, if not positively harmful to that stone; that almost the only one
that has been successful at all on these stones has been sulphur
dissolved in some compound, and applied to the stone so that the
sulphur itself was precipitated in its pores.   But even this does not seem
to have entered very far, and has not been successful unless the stones
put in place of those removed had been treated on all their six sides.
In that case the stone has been preserved, but how long it will remain
so it is impossible to tell.

With dolomite, in which there is a large excess of lime, the only
safety is to prevent the action of the carbonic acid contained in the air
by water-proofing the outside of the stone.   This can be less success-
fully accomplished, because, as the surfaces of attack are comparatively
large, the action is from the outside, and but little pitting takes place, as
the interlacing of the crystals makes cavities that never can penetrate
far into the stone.   Any coating applied to the outside will therefore be
likely to wear off after a time, and thus leave fresh surfaces of attack,
which do not at once become visible, as the surface is constantly kept
clean by the rain and the wind.

All the experiments made in Europe with the use of silicate of soda, or
water-glass, upon any building stones, except those in which lime and
magnesia were principal elements, have met with signal failure.   The
use of water-glass or siliceous material amounts to nothing on siliceous
rocks.   The silica becomes decomposed by exposure to the air, and forms
a sand which drops off, and the caustic alkali is washed out, or remains
behind to help the disintegration.   The only things which have been

successful have been those that prevented the attack of the acid gases or water from the surface or sides of the stone.

Water-proofing is best done by a compound of paraffine, sulphur, and oil, applied to the stones before they are put into the building, or else frequently applied to the surface after they are put in. In sandstones the sulphur is not necessary. Oil, with a certain amount of paraffine, may be used, providing the application is made hot. If, however, it is made cold, the preserving material sinks but a little way into the stone. If the stone is heated from the outside, with the intent to bring the surface of the stone up to such a point that it will heat the paraffine, there is great danger that the stone will suffer more from the remedy than from the disease.

There is no necessity for the decomposition of brownstone if the material is carefully selected. Every building that I have examined contains some stones that would last indefinitely, and if only those were selected from the quarry which have a siliceous cement, there would be no necessity for water-proofing, and we should not have the rapid destruction in beautiful structures which is so common in countries where sandstones are used. The same kind of external water-proofing must also be done upon dolomite and limestone, but efforts in this direction have been less successful than upon sandstones. Many methods for the prevention of disintegration have been tried, not only with no success, but with absolute failure.

DISCUSSION

ON THE CAUSE AND PREVENTION OF THE DECAY OF BUILDING STONES.

J. J. R. CROES, M. Am. Soc. C. E.—I would like to ask Professor Egleston with what kind of mortar he proposed to lay up his oiled stones?

Prof. EGLESTON.—I think any kind of mortar would answer perfectly, because the absorption of oil is not such as to prevent the chemical action in the mortar. The tendency of the oil would rather be to the center of the stone than to come out and affect the mortar.

M. J. BECKER, M. Am. Soc. C. E.—Would this treatment be possible with stones coming fresh from the quarry?

Prof. EGLESTON.—Quite possible. It is desirable, however, that all building stone should be tempered before it is used, that is left long enough in the air to lose its quarry-water.

J. F. FLAGG, M. Am. Soc. C. E.—I would like to ask whether soaking with oil in this way might not interfere with the adhesion of the cement?

Prof. EGLESTON.—I think not.

Mr. CROES.—Certainly it would not prevent the binding of the cement itself, but it seems to me that it would prevent that adhesion of the mortar to the stone which is essential to the mortar and the stone becoming one mass and holding firmly together.

Mr. FLAGG.—Would not this treatment of the stone with the oil disfigure its appearance.

Prof. EGLESTON.—There is a difference in the absorption of the oil, and this causes a slight difference in color, which, however, disappears in a few months. If the stone is allowed to remain in oil or in fatty material for months until thoroughly impregnated, it might prevent adhesion of the mortar for a while; but the object is not to soak the stone through, but only to allow it to take up so much oil as to prevent the action of the water from the outside and the dampness from the inside.

Generally the oil is applied after the building is erected, but it is much better to water-proof each block before it is used. The object of it in this case is to prevent any action of the atmosphere; in the other,

it is generally to replace the material already dissolved out by some substance, which will fill the pores so left and prevent further attack. The substances so used are oil, sulphur and paraffine.

F. COLLINGWOOD, M. Am. Soc. C. E.—I wish to inquire of Professor Egleston on which side of the building, which exposure, he found most decay, and whether the common impression that prevails among masons is correct, that the smooth dressing of stone causes it to be affected more quickly.

Prof. EGLESTON.—There is no doubt that the smooth dressing of stone which has already begun to decompose will make the decomposition go on more rapidly. As to your other point, the direction of the prevailing wind, which regulates the storms, is the one which affects the stone the most.

Mr. COLLINGWOOD.—I ask that question because Professor Trowbridge, in an address he made, said that a southerly exposure was the one that damaged the stone the most. He attributed it to the heat.

Prof. EGLESTON.—After the decomposition has taken place in this sandstone, with absorption of moisture in the winter time, there will be a certain amount of freezing, and when the stone is ready to decompose, that will hasten it. I have not followed the researches of Professor Trowbridge, but on the side of prevailing winds, stone always decomposes most rapidly. Decomposition also takes place on the side most exposed to the sun, as the stone is then alternately wet and dry.

THEODORE COOPER, M. Am. Soc. C. E.—They have removed from Trinity Church occasionally a stone, and they have redressed numbers of others. Now, what is the reason for that ? It is the same kind of stone, is it not ?

Prof. EGLESTON.—There are four different kinds of stone in Trinity Church. The contract was only for one, but it was not carried out. When the report of the cause of decay was made to the corporation, it was thought necessary to redress the stone previous to treating it. The decomposition has gone nearly into the interior of the stone, six inches in some cases, and it was found that some of the stones were so rotten that it was not worth while to redress them, and they were removed and new stones put in their place. It is true that stones when they are once dressed and have lost their quarry-water, and then redressed, will not stand as long as stones which are first dressed and then got their quarry hardening. Perhaps the most notable example of this is to be

seen in Paris, where the ordinary building stone is easily planed and sawed when first taken from the quarry; but if left long, the plane and the chisel are of little use, and they have to be cut as any other stone.

OBERLIN SMITH, M. Am. Soc. C. E.—I would like to know whether any experiments have been made by dissolving paraffine oils, which easily evaporate, and therefore get rid of the necessity of heat; and also whether there have been been any experiments with ordinary dust with the sand-blast instead of sand.

Prof. EGLESTON.—A large number of experiments have been made with paraffine and like compounds. They have had various results, according to the way the paraffine is applied. Some of them heat the stone in order to make the paraffine enter deeply into it. This is exceedingly dangerous when the stone has commenced to decompose, and is likely to increase rather than diminish the trouble, by causing expansion when the stone is already weak. When the stone is not heated the paraffine must be hot, and the application is best made in warm, dry weather. No substance known has the efficiency of paraffine. It is practically indestructible, and, if properly applied, it fills the pores and prevents any subsequent decomposition by the action of the weather. My intention, in studying the effect of abrasion, was to take ordinary flour, and my belief was that diamond could be worn away with ordinary flour; but since my first experiments were made, I have never found any one who would allow me to use the sand-blast sufficiently long to test it. I know that this statement seems incredible, but when the difference in hardness between ordinary sea-sand and the diamond is taken into account, and the fact is considered that with ordinary sea-sand the diamond has been worn away, it is quite credible that stone could be worn away with ordinary street dust, and much softer material. Street dust is much harder than the sand in the ordinary sand-blast. I have frequently made microscopic examinations of the ordinary street dust, and if any of you who live in New York will examine your window blinds after a rain storm, preceded by high wind, you will find them covered with minute particles of sharp quartz sand. There is also a considerable amount of iron filings besides organic dust. I believe firmly that if flour is hurled at stone with sufficiently great velocity, in a time easily named it will wear away the hardest of stone, or even the diamond.

PERCIVAL ROBERTS, M. Am. Soc. C. E.—I recollect a few years ago,

in connection with the electric light machines, that the comminutors, which were warranted not to wear away, were made with hard copper and the brushes with soft. It was found, however, that the comminutors wore away very fast. It was then reversed; the comminutors were made of soft copper and the brushes of hard, and the comminutors lasted much longer than before. It has also been found that the wear of hard steel rails is greater than the wear of soft steel rails. The fact seems to be that with hard and soft material in connection, the wear of the hard is greater than that of the soft.

Prof. EGLESTON.—I can explain Mr. Roberts' assertion. Any clock-maker sees these facts. The diamond saw is made of the softest copper that can be had. The fact of this wearing and cutting action can be seen in any old-fashioned clock escapement. The soft brass of which the escape wheel is made, frequently remains unacted on for 125 or 130 years, but the hard steel of the escapement is cut into so far as frequently to have the appearance of having been carefully filed. I recently made an examination of a clock of this kind, the escapement of which was deeply worn and the pinions of the escape wheel almost entirely cut through. The fact is that the soft material with the gummy oil holds the hard dust, as the copper of the diamond saw holds the diamond dust, and in this way grinds into the surface sometimes as far as one-sixteenth of an inch.

FREDERICK BROOKS, M. Am. Soc. C. E.—I would like to inquire what was the intention in painting the stone of the Capitol at Washington?

Prof. EGLESTON.—I think the original intention was only to make the old part agree with the new in color, but the oil of the paint preserved the stone from the action of the air, and it has since been used for that purpose.

Mr. FLAGG.—It was in such a bad condition that it was the only way to give it a respectable appearance.

MENDES COHEN, M. Am. Soc. C. E.—I have always heard that the first painting was done to the Capitol to restore the white surfaces that were destroyed with smoke in 1813.

CHARLES B. BRUSH, M. Am. Soc. C. E.—Does not this treatment shut up quarry-water in the stone, and is it not therefore injurious to the stone ?

Prof. EGLESTON.—The quarry-water is very small in amount in the stone, and evaporates after an exposure of only a few months. The ex-

perience in the English Houses of Parliament was, that unless the stones were treated on their six faces, they would flake and chip, as if they had not been treated, in the course of a very short time. The only thing that has stood is sulphur. Applications made to the exterior of the stone did not answer except the sulphur. The stone treated with sulphur lasted 30 or 40 years and has only just begun to flake. Paraffine has, to my knowledge, never been used on the House of Commons. If any of the processes that require the stone to be heated were used on that building they would do great harm.

W. H. BIXBY, M. Am. Soc. C. E.—I would like to know the effect of applying boiled linseed oil to marbles and other light materials ?

Prof..EGLESTON.—It is not generally applied to marbles at all. Its object is to replace something dissolved out. It darkens stones.

WM. P. SHINN, M. Am. Soc. C. E.—The Pittsburgh Court House, built in 1848, was built of Freeport sandstone. The columns, which were doric, I think, were painted immediately after they were erected. The result was a scaling of one-eighth to three-sixteenths of an inch off the whole surface of the columns, leaving them rough. I was not in Pittsburgh at the time the painting was done. The first time I saw the Court House was some five or six years afterwards. The stone-mason who erected it was a contractor under me in the construction of the Fort Wayne road, and stated, as his opinion, that the cause of the scaling was that the paint was put on before the evaporation of the quarry-water. I do not know as to his theory being correct, but I do know as to the scaling, and that the paint was put on immediately after the erection of the stone.

Mr. BECKER.—This stone is found in the neighborhood of Pittsburgh. It is a soft, oleaginous sandstone, and, while wearing but slowly, it soon shows unmistakable signs of decay from water and the elements. But that stone contains so large an amount of quarry-water that it is impossible to use it fresh from the quarry. The stone has to be seasoned from four to six months. If the stone is laid into the work direct from the quarry it will crack from frost, and I should think that stone containing such a large amount of water should have some treatment to eliminate that moisture before the remedy against decay is applied.

Prof. EGLESTON.—It certainly should. That amount is unusual.

Mr. BECKER.—Then there is another sandstone on the Ohio River, above Cincinnati, which is so largely charged with coal-tar that I have

frequently seen it drop down in large drops, so as to disfigure the whole face of the stone. For a season or two it actually runs down the face of the stone. Now how would that have to be treated?

Prof. EGLESTON.—I should not think such a stone as that needed any treatment at all. It is already treated. If such a stone is examined with a microscope, it would be found full of petroleum, and its compounds, which are the most serviceable materials to fill the cavities made by the solution of the binding material.

Mr. BECKER.—We have that stone in such large quantities that it constitutes almost the only available material for many railroad purposes in that vicinity. We are using it, with the precaution of seasoning it always for several months before we attempt to put it in a building.

Prof. EGLESTON.—I should think such a stone as that would certainly have to be seasoned. Does that stone decompose?

Mr. BECKER.—It decomposes from the surface, but so slightly that it would not be injurious in rough structures, such as railroad bridges.

Prof. EGLESTON.—It would be impossible to tell how to treat it without making a very careful examination to begin with.

WALTER KATTE, M. Am. Soc. C. E.—Have you had occasion to note or make mechanical or chemical experiments upon brick, terra cotta or beton?

Prof. EGLESTON.—Beton is artificial stone. Brick is very largely porous, and the stains which come upon bricks at the present time are entirely preventible. These stains are the result of a cheap method of making the lime and cement which are now used. Good brick and terra-cotta need no protection, but coating them would prevent the stains by preventing the percolation of the water.

Mr. FLAGG.—Will Professor Egleston explain how it is, that since carbonic acid is united chemically with the lime in limestone, the lime can be attacked and disintegrated by water containing the same acid?

Prof. EGLESTON.—All carbonates are more or less soluble in an excess of carbonic acid, and they are easily soluble provided the solution is dilute. When very concentrated they do not dissolve so easily. When limestone and dolomite occur together, one or the other of the two is apt to be in larger crystals. In the case of the marble altar tombstone in Trinity churchyard, the dolomite crystals are very large. The calcite is in small amount. The tombstone was originally polished, but all the calcite has been dissolved out, leaving dolomite crystals protruding, and

so rough that the slab looks as if it had never been polished. In the case of the stone from the quarries in Lee, Mass., of which the Capitol at Washington is built, the dolomite and limestone are together in crystals of about equal size. The stone in the quarry is filled with crystals of tremolite, which is a silicate of lime and magnesia, which is not attacked. Where the quarry stone is exposed to the weather for a long time, the lime has been entirely dissolved out, leaving the dolomite as a sand through which the tremolite crystals are scattered entirely detached.

T. H. JOHNSON, M. Am. Soc. C. E.—During my connection with the building of the Indiana State House we used large quantities of oolitic limestone, some of which was dressed by hand and some by machinery. In both cases it was found that the action of the tool left a thin skin of injured surface, which the first winter's exposure would remove. I found also that the stone-cutters use the word "stunned" to designate this injured surface. All workmen engaged in polishing marble, granite, and other stones susceptible of polish, recognize this effect of the tool, and know a good polish is impossible until the whole depth of the "stunned material" has been rubbed down.

Mr. FLAGG.—This skin that comes off, does it apply to the machine-dressed or the hand-dressed, or to both?

Mr. JOHNSON.—To both. In this connection I would also state that I made a series of tests upon the transverse strength and modulus of elasticity of various building stones. Among the samples tested were a large number of oolitic limestones, some of which had been dressed by hand and some had been sawed. I found in all cases that both the strength and elasticity had been impaired by the tool dressing, so that the modulus of transverse rupture and the modulus of elasticity were both reduced to two-thirds of the corresponding moduli of sawed samples.

Mr. COLLINGWOOD.—That would seem to show that the results in our text books, which have been produced by very finely dressed specimens, must be very inaccurate if they are only two-thirds of the strength they really possess, when there is no injury to the surface.

Mr. CROES.—I regret to say that I do not thoroughly understand yet the distinction between theory and practice as given by Professor Egleston. These stones which have been preserved by various methods, or which have not been preserved at all, and which have shown disintegration, are stones, as I understand, that have been laid in walls for a long

period of time. I may be mistaken, but I have not understood that stones which have been saturated on all sides with such a preparation as the Professor recommends have been tested for any length of time, have been laid up in a wall, and have proven that they will not deteriorate. The processes of preservation that have been applied have been applied to the faces of walls, and have either failed or succeeded, as the case may be, in the instances mentioned. Now, if I am correct in this supposition, that this process of saturation of the stone or impregnation of the stone with an oleaginous substance has not been tested in masonry, I cannot understand how a good bond can be procured in masonry, in which the mortar mixed with water is brought in contact with the oily surface of the stone. I do not believe that it will take a good bond in the absence of evidence to the contrary.

Prof. EGLESTON.—I thought I had made that plain. I intended to state it, that the only successful experiments on the Houses of Parliament were those in which a preserving material had been applied to the whole surface of the stone, that is all the surface of each of the six sides. The only exception was of those treated with sulphur. Stones have stood for 20 years, the surface of which only was impregnated with sulphur, but these have just commenced to chip in July last. Every other stone that was put into the Houses of Parliament that has not been treated on all its surfaces, has failed. Those treated on all their surfaces have not failed.

Mr. CROES.—Have those stones been treated with oil?

Prof. EGLESTON.—They have been treated with oil and substances of that character.

Mr. CROES.—I understood that the stones were treated with sulphur.

Prof. EGLESTON.—That was only on the outside of a portion of one of the buildings, and was done about twenty years ago.

Mr. JOHNSON.—We have in Ohio a variety of sandstone which is more or less impregnated with saltpetre. What would be the effect of the combination of oil with saltpetre?

Prof. EGLESTON.—I do not know, never having tried it, but I think the effect would be that the oil would be decomposed, as the saltpetre would come out on the surface. So far as my experience goes, the only thing that can be done to preserve stone is to prevent the action of atmospheric influences, those that go from the outside in. If there is anything in the stone to come out it has got to come out. I do not

know of any method of preserving stone except to prevent the influence of the atmosphere working from the outside in. Of course it would be quite possible to preserve the stone by taking all the saltpetre out, but it would not be practicable; it would be too expensive.

D. J. WHITTEMORE, M. Am. Soc. C. E.—This impregnating of stone with oils or things of that nature I think is nothing new. I think that Vitruvius, or some of the ancient writers, describes processes for the manufacture of cement by which there was introduced hog's lard or olive oil, and the mortar was used principally for the purpose of lining the aqueducts; and, judging from a specimen of the mortar, it bears out conclusively that such matter was used, as the oily substance has vanished, and it is porous now, more open probably than the ordinary brick. Such substances might, in my opinion, have a temporary effect towards preventing disintegration. As to permanent effect, I think the question is yet to be solved.

F. G. DARLINGTON, Jun. Am. Soc. C. E.—I do not know whether there are any data to show the cost of the application of any of the preservatives to any of the stone, and the question arises whether it would not be cheaper in the first place to pick a stone that would stand the atmospheric influences rather than to take a stone that would not and treat it with substances to preserve it.

Prof. EGLESTON.—There is no question about that. As the stones come from the same quarry, the cheapest and best way is to pick the stone that will stand and reject absolutely every stone that will not stand, and if that was done no sandstones would be used except those having a siliceous binding. It is moreover quite possible to fill the pores of a stone, whether they were in the stone in the quarry or have been formed by atmospheric influences, by sulphur or paraffine, which will not decompose. Oil is a palliative and arrests decomposition temporarily, but when the gum which it forms is decomposed, the coating must be repeated or the action will commence again.

Mr. BRUSH.—If I understand the Professor, the treatment he proposes, that is, oil on the outside of the stone, does not prevent moisture leaving it. If that is a fact, it relieves my mind from the embarrassment of the possibility of confining the moisture in the stone.

Prof. EGLESTON.—I did not say moisture. The nitre is nitrate of potash or nitrate of soda. The ordinary nitrate of commerce is nitrate of potash, and there is no power that will prevent its coming out if the

materials that form it are in the stone itself. The nitrates, when they exude, will form a soap with the oil, which will be washed away.

Mr. BRUSH.—It seems to me very undesirable to do anything to stone that would be the same as painting would be to wood. If you confine the moisture it would have a serious effect, and severe cold would break the stone.

Mr. DARLINGTON.—I would like to know what would be the effect of extreme heat upon stone treated with any of those preservatives. If with linseed oil, would not the heat of our extreme summers have the effect of bringing the oil all out ?

Prof. EGLESTON.—So far as any experiments have been made, I think it is exactly the contrary. The higher the heat the further the oil pene- trates the stone. Experiments have been made up to about 250 degrees; not much higher than that, because a higher heat would injure the stone, but the penetration is greater as the heat upon the stone is higher. Small pieces of stone can be treated in the laboratory to this tempera- ture, or even above it, without much danger. When large pieces are treated on the surface by means of flame thrown on it, the heat must of necessity be applied over moist surfaces, and the danger of damage will always be very great. When the stone is heated by the sun, the temper- ature will often be very high without danger to the stone, and as the heat has penetrated under such circumstances to a considerable depth, the penetration will be greater than is possible by artificial means, especially in buildings.

O. J. H. WOODBURY, M. Am. Soc. C. E.—I have had some experience in the protection of a brick building by the use of a plaster composed of boiled linseed oil mixed with sand colored with red lead, the color after drying being similar to the Portland sandstone. A coat of boiled linseed oil was laid upon the brick wall before the mixture was applied. A covering of this material upon a building has resisted the weather for three years without any chipping, cracking, spotting or disintegration of any kind.

Reference was made in the paper to the slates formerly used as grave-stones throughout New England. There is quite a difference in the ability of the product of various quarries to resist the weather.

A number of years ago there was a slate quarry in the southern por- tion of New Hampshire which was held in great reputation for its headstones, which would wear as smooth as glass upon exposure to the

weather, while the production of other slate quarries would wear rough, although slowly.

The oldest headstone in this country, as far as I have any means of knowing, is in the Western burying ground at Lynn, Mass., and dates back to 1628. It is still smooth and perfectly legible. It may be an' act of vandalism, but some of these ancient headstones, which have attested their quality through many years, have been appropriated, redressed, and used as tablets in more pretentious monuments of later date.

Mr. CROES.—I saw a statement in one of the New York papers a few months ago to the effect that the surface of the obelisk in Central Park was disintegrating from the effects of this climate.

Prof. EGLESTON.—That is true, and the disintegration is very rapid, but from a different cause altogether. That stone has been exposed for two thousand years to a dry climate at a high temperature, and the disintegration of the granite had already commenced before it came here. It had probably stood for two thousand years, and would probably have disintegrated in two thousand years more; but it has been brought to the very worst climate in the world, I suppose, except Boston, and now any one who goes there after a storm can pick up as many pieces as he pleases, and can get relics very easily. I have very little hesitation in saying that if the obelisk is not placed under some dome, the dome of the Museum of Art, as it should have been in the first place, in twenty or thirty years it will probably be beyond repair.

Mr. CROES.—How large pieces are coming off?

Prof. EGLESTON.—From the size of a pea to pieces several inches long.

Mr. CROES.—On which side of the obelisk?

Prof. EGLESTON.—In all directions. It does not seem to be from one side more than another. In regard to the slates of which Mr. Woodbury speaks, I have had the same experience in roofing. The roof of my country place twenty years ago was covered with the best slate I could get from the Canaan quarry. I examined that slate lately and found some of it no better than clay. Some of it had all gone to pieces so that you could crumble it in your fingers. I have not completed my investigation in regard to the causes of the disintegration of slate. I simply wish to call the attention of engineers to the fact that water-proofing alone will arrest the process of decomposition.

Captain BIXBY.—The effect of the atmosphere upon granite and other stones is shown very clearly also on iron at Fort Macon, North Carolina.   The fort is of old-style masonry, inside of brick.   Many of those bricks that come out to the face of the wall as headers are so soft that you can stick in a lead pencil almost anywhere and take out half an inch of the brick.   The iron balustrade going up the side of the steps to the upper parade on the side where the southeast winds can strike it has wasted away under that wind, so that iron bars one inch square in a vertical position have been completely rusted through.   Some of them are standing there now in that way.   The middle part of the bar is gone, and you can see the evidence of rust and the corroding action of the atmosphere to show that that is the way the bars have disappeared, and not from any other cause.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

342.

REPORT OF PROGRESS BY THE COMMITTEE ON THE COMPRESSIVE STRENGTH OF CEMENTS AND THE COMPRESSION OF CEMENTS AND SETTLEMENT OF MASONRY.

PRESENTED AT THE ANNUAL CONVENTION AT DENVER, COLO., JULY 5TH, 1886.

Your Committee beg leave to submit the following as a report of progress in their work. For various reasons, unnecessary to enumerate, the work thus far done has been only that of accurate study of previous investigations, and a discussion between the Members as to apparatus and methods, which it is hoped will bear fruit in the future.

As some interesting results have been obtained by other experimenters, the Committee deem it desirable to give a summary of some of them, as they have not been brought prominently to notice heretofore.

In a pamphlet issued by the "Commissioners for the Erection of the Public Buildings" in Philadelphia (J. J. McArthur, Jr., architect), is given a series of experiments at the Watertown Arsenal on building-stones, cast and wrought-iron, bricks and brick piers set in cement-mortars.

As to the specimens of stone tested, the compression is not given; they were all in 6-inch cubes. We give the summary of results, since they

tend to show that large specimens give greater proportionate strength than smaller ones, the results being higher then ordinary.

TABLE No. 1.

From pamphlet of " Mechanical Tests of Building Material made at the Water-town Arsenal by the United States Ordnance Department at the request of the Commissioners for the Erection of the Philadelphia Public Buildings, John McArthur, Jr., Architect."

MARBLE.

Locality.	Color.	Direction of Pressure.	Total Load Applied.	Crushing Force on a Square Inch, in lbs. Avoirdupois.	Sectional area, in Square inches.	REMARKS.	Register Number of Experiment.
Lee, Mass..........	Blue ...	End......	715 000	20 504	34.87	Burst into fragments	2550
"	White..	Bed......	800 000	22 370	35.16	Slight flaking on one face	2551
"	W. & B.	End......	800 000	22 860	34.99	Without apparent injury	2565
"	White..	"	800 000	22 820	35.05	" "	2566
"	Blue ...	Bed......	800 000	22 900	34.93	Flaked off along one edge	2567
"	W. & B.	"	767 000	21 700	35.34	Crushed suddenly....................	2568
Montgomery Co. Pa.	Blue ...	"	466 300	11 470	40.64	Failed suddenly	2552
"	"	...End......	400 000	10 420	38.40	"	2554
"	"	...Bed......	543 000	13 700	39.63	Ultimate strength...................	2569
"	"	...End......	398 000	10 120	39.33	"	2570
"	"	... "	347 500	9 590	36.24	"	2571
"	"	...Bed......	434 000	10 940	39.67	"	2572

LIMESTONE.

Locality.	Color.	Direction of Pressure.	Total Load Applied.	Crushing Force on a Square Inch, in lbs. Avoirdupois.	Sectional area, in Square inches.	REMARKS.	Register Number of Experiment.
Conshohocken, Pa..	....	End......	494 000	14 090	35.05	Ultimate strength...................	2557
"	....	Bed......	566 000	16 340	34.63	"	2558
Indiana............	....	End......	377 000	8 530	44.22	"	2575
"	....	"	320 500	7 190	44.56	"	2576
"	....	Bed......	321 000	7 776	41.38	"	2577
"	....	"	438 300	10 620	41.28	"	2578

DOVE-COLORED MARBLE.

Locality.	Color.	Direction of Pressure.	Total Load Applied.	Crushing Force on a Square Inch, in lbs. Avoirdupois.	Sectional area, in Square inches.	REMARKS.	Register Number of Experiment.
Vermont............	....	Bed......	531 200	13 400	39.65	Ultimate strength	2579
"	....	End......	379 800	9 870	38.48	"	2580

SANDSTONE.

Locality.	Color.	Direction of Pressure.	Total Load Applied.	Crushing Force on a Square Inch, in lbs. Avoirdupois.	Sectional area, in Square inches.	REMARKS.	Register Number of Experiment.
Hummelstown, Pa.	....	Bed......	528 700	12 810	41.28	Ultimate strength	2555
"	....	End......	570 300	13 610	41.92	"	2556
Ohio	Buff...	Bed......	256 000	6 510	39.32	"	2563
"	"	...End......	199 500	4 860	41.02	"	2564
"	"	...Bed......	289 500	7 020	41.25	"	2573
"	"	...End......	160 000	3 940	40.06	Bearings imperfect..................	2574
"	Blue ...	"	305 000	7 680	39.68	Ultimate strength	2581
"	"	...Bed......	435 400	10 400	41.90	"	2582
"	"	...End......	391 800	9 795	40.00	"	2583
"	"	...Bed......	351 000	8 710	40.30	"	2584
"	"	...End......	672 100	16 280	41.28	Fractured suddenly with loud report.	2585
"	"	...Bed......	493 500	12 420	39.74	Ultimate strength	2586

BRICK.

Manufacturer.	Quality.	Make.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample Inches.	REMARKS.	Number of Experiment.
Dobbins	Hard	Machine	288 500	8 610	33.50	Failure gradually took place	2559
"	"	"	411 000	11 720	35.07	Failed rapidly near close of test	2587
"	"	"	304 000	9 210	33.00	Ultimate strength	2588
Excelsior	"	"	261 000	8 310	31.39	Failed by breaking up	2560
"	"	"	180 200	5 540	32.53	Ultimate strength	2589
"	"	"	188 100	5 790	32.51	"	2590
J. R. Huhn	"	Hand	591 000	18 690	31.63	Failed suddenly at very end of test	2561
"	"	"	346 400	10 970	31.57	Ultimate strength	2591
"	"	"	654 000	20 830	31.4	"	2592
"	"	"	364 000	11 150	32.64	"	2593
"	"	"	382 000	11 650	32.8	"	2594
Dotterer	Pressed	Machine	256 500	7 770	33.03	"	2562
"	"	"	304 000	9 030	33.6	"	2595
"	"	"	243 000	7 210	33.70	"	2596

CAST-IRON.

Form of Specimen.	Diameter.	Length.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample in Inches.	REMARKS.	Number of Experiment.
Solid cylinder	3"	5".998	501 000	60 360	8.3	Oblique fracture. Sides swelled	2597
Open cylinder	4".41	6".001	566 000	68 190	8.3	Sides swelled	2598
"	8".78	5".998	657 600	79 230	8.3	Fractured into twenty-five pieces	2599

WROUGHT-IRON.

Form of Specimen.	Height.	Length.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample in Inches.	REMARKS.	Number of Experiment.
Rolled I-beam	7".05	6".004	282 000	54 230	5.2	Flanges buckled outwards	2600
"	9".00	6".000	353 000	54 310	6.5	" "	2601
"	15".25	6".002	800 000	53 330	15.	Web and flanges buckled	2602

Three of the tests of marble from Lee were with the grain, and three across the grain, but there was no appreciable difference in strength.

Of the marble from Montgomery County, Pa., the strength was greatest when on the bed.

Of limestone from Conshohocken, Pa., the strength on bed was 16 340, and on end 14 090 pounds.

Limestone from Indiana gave on end 7 190 to 8 530 pounds, and on bed 7 776 to 10 620 pounds.

Vermont dove-colored marble gave on end 9 870, and on bed 13 400 pounds.

Sandstone from Hummelstown, Pa., 12 810 on bed and 13 610 on end.

Sandstones from Ohio, 5 specimens on end gave an average of 8 711, varying from 3 940 to 16 280 pounds, and 5 on bed gave 9 012 pounds, varying from 6 510 to 12 400 pounds. Some of the specimens began failing at 1 000 to 1 500 pounds less.

Of bricks, hard-burned, machine-made Philadelphia bricks crushed at (in full size) 5 540 pounds to 11 720 pounds per square inch, the average of six being 8 197 pounds, and the lowest pressure at which there was any sign of failure was about 3 000 pounds.

Of machine-made pressed Philadelphia brick, the strengths were 7 200 to 9 050 pounds per square inch, the average of three being 8 010 pounds, and the lowest pressure at first failure 2 500 pounds.

Of hand-made Philadelphia bricks the strengths were 10 970 pounds to 20 830 pounds per square inch, the average of five being 14 658, and the lowest pressure at which failure began 3 000 pounds, all others being much higher, 6 300 pounds and over.

A solid cylinder of cast-iron 3 inches in diameter and 6 inches long, crushed at 60 360 pounds per square inch. Hollow cylinders of same length and area of section, 4½ inches in diameter, failed at 68 190 pounds, and 8¾ inches diameter at 79 230 pounds, the limit of elasticity being at about 15 000 pounds.

Rolled I beams 7 to 15 inches, in 6-inch lengths, failed by buckling at about 54 000 pounds, with elastic limit in one case of 10 000 pounds, but yet not increasing perceptibly up to 28 000, and in the others of about 30 000.

In none of the experiments thus far mentioned is the change of dimensions under compression given.

The remainder of the experiments were on brick piers, five bricks high and one and a half bricks square, thoroughly bonded, and laid in cement or lime-mortar.

The cement-mortar consisted of "1 part Rosedale cement (Valley brand) to 2 parts sharp bar sand." The lime-mortar of 1 part "Cedar Hollow" lime, from Chester County, Pa., to 4 parts of same sand. The piers were all a week short of 15 months' old, and set in the air. The following table gives a summary of results.

TABLE No. 2.—GENERAL ABSTRACT.

Official No. of Test.	Maker of Bricks.	Mortar.	Area in Square Inches.	Snapping Sounds.	Per Square Inch.	Cracked.	Per Square Inch.	Total Compression at 50 000 lbs. on Specimen.	Set at 50 000 lbs. on Specimen.	Pounds per square inch at 50 000 on Specimen.	Ultimate Strength.	Per Square Inch.
3255	Dobbins	Lime	165.75	85 000	512	110 000	663	.0220	.0130	302	239 000	1 442
3256	"	"	162.56	150 000	922	150 000	922	.0180	.0100	308	259 100	1 594
3257	"	Cement	169.00	142 000	840	180 000	1 065	.0180	.0060	296	356 900	2 112
3258	"	"	162.56	300 000	1 845	300 000	1 845	.0150	.0075	308	420 000	2 584
3259	Huhn	Lime	156.25	78 000	499	160 000	1 024	.0210	.0110	320	299 000	1 914
3260	"	Cement	159.38	320 000	2 070	320 000	2 070	.0160	.0070	320	428 000	2 685
3261	Dotterer	"	156.25			150 000	960	.0210	.0080	320	250 000	1 600
3262	"	Lime	156.25			127 000	768	.0165	.0070	320	182 400	1 167
3263	Excelsior	Cement	162.56	100 000	627	240 000	1 476	.0160	.0075	308	268 900	1 654
3264	"	"	159.38			220 000	1 380	.0140	.0065	314	266 500	1 672
3265	"	Lime	158.76			160 000	1 070	.0240	.0130	315	178 800	1 126
3266	"	"	156.25			100 000	640	.0280	.0165	320	124 900	699

ABSTRACT OF AVERAGE STRENGTHS.

In Lime-mortar. *First crack*.......... 864.23 pounds square inch, or 62.226 tons square foot.

" Cement " " .... 1 567.56 " " 112.864 " "

In Lime-mortar. *Ultimate strength*.... 1 375 pounds square inch, or 99 tons square foot.

" Cement " " .... 2 141.4 " " 154.18 " "

JOHN McARTHUR, JR.,
Architect.

From this, and the more detailed results given in the pamphlet, we deduce the following statement:

Of the six piers set in lime-mortar, the first snapping sounds were heard with a pressure on specimens of 499 to 1 070 pounds per square inch, the average of all being 735 pounds.

The first perceptible crack occurred with 848 pounds average pressure, and the average crushing strength was 1 360 pounds.

The first perceptible permanent set was measured at 302 to 320 pounds pressure, this being 50 000 pounds on specimen, at which time the total compression was 0.0165 to 0.0280 inch on 12⅜ inches, or an average on all of 0.0216 inch, giving a co-efficient of compression of 0.00054 per 100 pounds of applied weight. The compression continued quite uniform up to the time when the first snapping sounds were heard, at which time the average of all gave a coefficient slightly less, or 0.000495 per 100 pounds, after which it increased.

Of the six piers set in cement, the first permanent set was at 296 to 320 pounds, with an average of 311 pounds. The total compression under this pressure was from 0.0150 inch to 0.0230 inch, with an average of 0.0178 inch and an average coefficient of 0.00045. The first snapping sounds were heard at 627 to 1 845 pounds, with an average of 1 300 pounds, and an average coefficient of compression of 0.0003.

Since the compression is in all cases greatest under the initial load, it is reasonable to conclude that the joints compress at first more than the bricks. This is also shown by the greater amount of compression of the specimens set in lime-mortar.

The first perceptible crack occurred under loads from 960 to 2 070 pounds, with an average of 1 466 pounds per square inch.

Professor Swain and Captain Maclay, of the Committee, have both made translations from the German of some interesting results obtained by Professor Bauschinger, of Munich. These were published in the "Mittheilungen aus dem Mechanisch-Technischen Laboratorium, der Kœnigl. technischen Hochschule in Munchen." (Heft. VII.)

The tests made included those for tension, compression, shearing, flexure, adhesion, behavior during setting, etc. They were made on seven different brands of Portland cement (six German and one French).

For behavior during setting glass cylinders $2\frac{6}{10}$ inches high, $2\frac{6}{10}$ inches in diameter were used, but it is not stated whether the setting occurred in air or water—probably the former. The results reached differed widely from those of Mr. Eliot C. Clarke, M. Am. Soc. C. E., who determined that all cement setting in water expanded slowly for about two weeks (see Transactions Am. Soc. C. E., 1885, pp. 167-8). Professor Bauschinger found that out of 28 different mixtures, in the case of only 7 were all the glasses broken even after 80 days, while with 3 no glasses

were broken, and with 6 only 1. In 11 cases a glass was broken after 60 days, and at the end of 80 days 60 out of 132 remained unbroken. As these results are not quantitative as to expansion, they are too indefinite to be of much value.
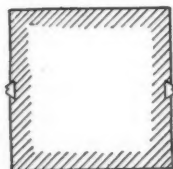
Fig. 1.

Fig. 2, page 725, shows the apparatus designed for measuring the changes of dimension occurring as hardening progresses; the first measurement being made 48 hours after moulding the specimen, or 24 hours after the insertion of the small metal pieces (see Fig. 1) having conical depressions, between which all measurements were taken.

The measuring apparatus consists of a U-shaped piece AA, having in one arm a thread cut for the insertion of a micrometer screw. On the screw is the wheel B, $\frac{1}{100}$ of a revolution of which can be read directly and $\frac{1}{1000}$ easily estimated. On the other arm of AA is a multiplying lever DD, whose shorter (lower) arm rests in one of the conical cavities in the specimen, while the longer arm traverses the scale F on the frame-like extension upward of the piece AA. The spring E attached to this frame, keeps the lever in contact with the specimen. The steel joint of the micrometer screw is in contact with the other end of the specimen.

To prevent any possibility of pressure other than a definite strain of contact, the whole weight of the U and attachments is balanced about the pivot a by the adjusting weight G, and the whole weight on the pivot a is suspended by the rod H from the lever J, bearing a second adjusting weight, K. The rod H has ball and socket joints at both ends. It will be seen that by turning the micrometer screw until the index is in the center of the scale F, and making proper allowances for the differences in temperature between the apparatus and the specimen, and also for changes in temperature as the experiments are made (since brass and cement expand differently), the exact changes of length can be determined.

The humidity of the air was found to exert no effect upon the specimen, but specimens immersed in water changed much more than those kept in air.

Five specimens were made of each kind and each mixture of cement, being cubes of $4\frac{72}{100}$ inches on a side; 3 of these were allowed to harden

TABLE No. 3.

Increase or decrease of the side of a cube measuring originally 12 centimeters (4.72 inches), given in thousandths ($\frac{1}{1000}$) of a millimeter from second day after mixing up to 16 weeks. + denotes increase. — denotes decrease.

Mark of Cement.	Cement in Liters.	Sand in Liters.	Weight of Sand and proportion of Water in it.	Amount of Water used in mixing Mortars, in Liters, and percentages. Liters. Per cent.	4 days in Air.	4 days in Water.	1 week in Air.	1 week in Water.	2 weeks in Air.	2 weeks in Water.	4 weeks in Air.	4 weeks in Water.	6 weeks in Air.	6 weeks in Water.	8 weeks in Air.	8 weeks in Water.	16 weeks in Air.	16 weeks in Water.
A	1	0	The sand weighed 1,217 kilo. per liter, and contained 5.55 per cent. water.	0.276 = 20.8	—1	...	+2	+16	—8	+22	—29	+27	—55	+36	—69	+23	—164	+44
	1	3		0.370 = 27.8	—3	+3	—7	—1	—8	—1	—49	+6	—80	+10	—100	+11	—160	+1
	1	5		0.460 = 34.6	—0	—1	—3	—6	—11	—6	—51	—19	—70	—16	—86	—31	—117	—32
B	1	0	1,245 kilo, with 4.68 per cent. water.	0.300 = 23.2	+10	+15	—15	+34	+3	+89	—16	+113	—49	+131	—74	+144	—206	+184
	1	3		0.370 = 28.7	+2	+3	—3	+8	+4	+8	—48	+16	—66	+12	—77	+19	—126	+24
	1	5		0.410 = 35.6	+1	+4	+4	+17	—11	+14	—67	+14	—65	+14	—68	+21	—111	+27
C	1	0	1,252 kilo with 4.95 per cent. water.	0.244 = 18.5	+7	+13	+7	+17	—11	+36	—39	+38	—57	+30	—80	+46	—148	+55
	1	3		0.360 = 27.2	+3	+3	+4	+30	—13	+3	—43	+3	—69	+10	—81	+5	—135	+10
	1	5		0.410 = 31.0	+5	+5	+7	+4	—24	+8	—52	+6	—72	+9	—89	—2	—126	—2
D	1	0	1,269 kilo, with 4.73 per cent. water.	0.234 = 19.4	+5	+8	+14	+16	—42	+16	—51	+22	—73	+32	—105	+32	—222	+43
	1	3		0.340 = 28.1	+1	+1	—1	—8	—5	+5	—40	+11	—61	+8	—91	+4	—124	+2
	1	5		0.400 = 33.1	+1	+1	—12	+9	—46	+2	—82	+1	—102	—25	—127	—1	—154	+3
E	1	0	1,263 kilo, with 5.55 per cent. water.	0.302 = 23.9	+7	+7	—51	+32	—93	+38	—180	+15	—232	+25	......	+15	—407	+23
	1	3		0.390 = 30.8	+3	+14	—15	—0	—25	+6	—79	+8	—93	+4	......	+2	—157	+3
	1	5		0.460 = 38.7	+2	+3	—15	+2	—27	—7	—66	+11	—97	+6	......	—0	—164	+4
F	1	0	1,251 kilo, with 5.31 per cent. water.	0.270 = 21.4	—13	+5	—27	+13	—54	+11	—76	+21	......	......	—115	+15	+164	+26
	1	3		0.350 = 27.7	—7	+1	—13	+8	—41	—0	—62	+3	......	......	—110	+2	—144	+12
	1	5		0.430 = 33.2	—9	+3	—25	—11	—52		—82	+11	......	......	—127	+0	—166	—7
G	1	0	1,283 kilo, with 5.80 per cent. water.	0.300 = 22.9	—23	+3	—31	+4	—65	+7	—76	+24	......	......	—155	+31	—288	+15
	1	3		0.400 = 30.6	—10	+6	—28	+6	—59	+5	—85	+4	......	......	—131	+14	—177	+2
	1	5		0.480 = 36.7	—5	+8	—14	+1	—37	+6	—64	+4	......	......	—108	+2	—131	+9
H	1	0	1,287 kilo, with 5.57 per cent. water.	0.250 = 19.6	—13	+7	—35	+2	—44	—13	—73	+10	......	......	—146	+28	—257	+30
	1	3		0.350 = 27.5	+1	+10	—16	+9	—17	—15	—67	+11	......	......	—107	+20	—145	+11
	1	5		0.430 = 33.7	+3	+7	—12	+3	—22	+11	—51	+7	......	......	—101	+14	—126	+0
R	1	0	1,276 kilo, with 5.41 per cent. water.	0.245 = 19.8	—18	+3	—14	+16	—40	+23	—56	+23	......	......	—128	+18	—203	+23
	1	3		0.380 = 27.6	+6	+1	+7	+23	—16	+21	—25	+29	......	......	—78	+30	—101	+27
	1	5		0.120 = 33.9	+6	+1	+3	+14	—5	+19	—24	+21	......	......	—73	+18	—97	+16

in air and 2 in water, and measurements were made at intervals, with the results shown in Table No. 3.

It will be seen that the amount of water contained in the sand was in every case noted, as well as the water added in making the mortar.

The results may be summarized thus:

First.—In case of all three proportions of cement and sand, the specimens hardening in air show a progressive contraction with age, sometimes with a very slight preliminary expansion up to an age of about one week.

Second.—The total effect at the end of sixteen weeks, with mortars hardening in air, is in every case a contraction.

Fig. 2.
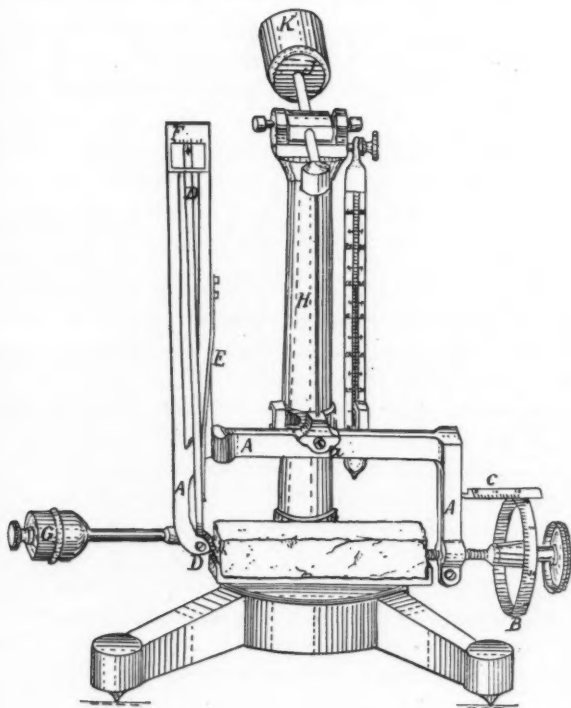
Third.—This total contraction is generally greatest with neat cement, and it decreases as the proportion of sand is increased. In a number of cases, however, the adding of sand appears to accelerate the contraction during the first four weeks, making it greater as the proportion of sand is increased.

Fourth.—The total contraction after sixteen weeks, for mortars hardening in air, varies as follows:

1 of cement to 0 of sand	from	.148 mm. to .174 mm.	or from 0.12 to 0.34 of 1 per cent.
1 "	" 3 "	"	.101 mm. to .177 mm.	"	0.08 to 0.15	"	"
1 "	" 5 "	"	.097 mm. to .166 mm.	"	0.08 to 0.14	"	"

Fifth.—With cement hardening under water, the phenomena are much more irregular. In general there is a continued expansion, but in a few cases at the end of sixteen weeks it was practically nothing.

Sixth.—The expansion under water is in every case greatest and most regular with neat cement, increasing progressively with age. As the amount of sand is increased, the expansion diminishes and becomes irregular.

Seventh.—The total expansion of cement hardening under water is as follows:

1 of cement to 0 of sand	from	0.15 mm. to 0.184 mm.	or from 0.01 to 0.15 of 1 per cent.
1 "	" 3 "	"	— 0.003 mm. to 0.027 mm.	"	0.0 to 0.02	"	"
1 "	" 5 "	"	— 0.032 mm. to 0.027 mm.	"	—0.03 to 0.02	"	"

The fact that there is an expansion in water and a contraction in air may account for the discrepancies between Mr. Clarke's and Professor Bauschinger's experiments. Mr. Clarke gave the expansion on a 10-inch cube as one-tenth of one per cent.

In Volume LXII, page 108, of Proceedings of the Institution of Civil Engineers, in a paper by Mr. John Grant, is a table of experiments on prisms, 4 inches long and 2 inches square, hardening in water for various periods, from one week to twelve months. (Table No. 4.)

The table gives the results, from which the author draws the following conclusions:

1. All cements expand more or less when hardening under water.

2. The expansion of good cement is so very slight, that in practice it need hardly be taken into consideration.

3. The expansion is greatest when the increase of strength is most active.

4. It diminishes in proportion to the admixture of sand.

TABLE No. 4.

Showing the Amount of Expansion in Twelve Varieties of Cement, Neat, and Mixed with Three Parts of Sand.—(From Min. Proc. Inst. C. E., Vol. LXII, p. 170.)

A prism of 10 centimeters = 3.9368 inches in length and 5 centimeters square, lying in water, expands (millimeters)

Sort of Cement.	Residue on sieve of 900 meshes sq. ctm., = 5 806 per sq. in.	Time of setting minutes.	Neat Cement.							Three of Standard Sand.							REMARKS.
			One week.	From one to four weeks.	From one to three months.	From three to six months.	From six to nine months.	From nine to twelve months.	Total.	One week.	From one to four weeks.	From one to three months.	From three to six months.	From six to nine months.	From nine to twelve months.	Total.	
A	5.0	240	0.0254	0.0228	0.0233	0.0067	0.0184	0.0100	0.1066	0.0134		0.0003	0.0050	0.0033	0.0037	0.0317	Same cement, but 2 months older.
B	8.5	30	0.0471	0.0198	0.0140	0.0135	0.0186	0.0097	0.1227	0.0073		0.0013	0.0000	0.0007	0.0000	0.0100	The same cement, with 1 per ct. of gypsum.
C	7.5	660	0.0141	0.0145	0.0081	0.0177	0.0107	0.0048	0.0702	0.0172		0.0023	0.0006	0.0033	0.0044	0.0316	Do. with 2 per cent. of gypsum.
D	10.7	35	0.0467	0.0450	0.0217	0.0341	0.0260	0.0132	0.1807	0.0392		0.0048	0.0038	0.0033	0.0037	0.0574	Do. with 5 per cent. of gypsum.
E	12.5	540	0.1217	0.0322	0.0173	0.0195	0.0080	0.0037	0.2024								
F	12.7	600	0.0230	0.0177	0.0170	0.0170	0.0030	0.0130	0.0907	0.0094	0.0025	0.0000	0.0011	0.0087	0.0000	0.0217	
G	5.2	35	0.0439	0.0415	0.0245	0.0226	0.0212	0.0115	0.1652	0.0044	0.0040	0.0000	0.0000	0.0005	0.0028	0.0117	
H	8.5	600	0.0140	0.0121	0.0041	0.0108	0.0089	0.0093	0.0592								
I	9.8	480	0.0240	0.0229	0.0118	0.0120	0.0055	0.0080	0.0842	0.0164	0.0092	0.0061	0.0053	0.0059	0.0043	0.0432	
K	9.8	20	0.0694	0.0437	0.0396	0.0278	0.0187	0.0150	0.2132	0.0117	0.0074	0.0037	0.0079	0.0035	0.0045	0.0447	
K¹	9.8	210	0.0317	0.0299	0.0262	0.0229	0.0115	0.0050	0.1272	0.0266	0.0160	0.0000	0.0034	0.0025	0.0108	0.0497	
K²	9.8	360	0.0897	0.0679	0.0406	0.0247	0.0248	0.0105	0.2542	0.1396	0.3035	0.0000	0.0024	0.0026	0.0039	0.4719	
K³	9.8	600	0.0960	0.0625	0.0335	0.0274	0.0164	0.0193	0.2551	0.0168	0.0124	0.0097	0.0043	0.0030	0.0010	0.0457	
K⁴	9.8	840	0.4131	1.0335	0.3122	0.0207	0.0100	0.0139	1.4029								
L	7.3	120	0.0428	0.0449	0.0313	0.0277	0.0080	0.0030	0.1597	0.0178	0.0024	0.0027	0.0043	0.0030	0.0040	0.0392	L cement,
L¹	7.3	420	0.0543	0.0499	0.0322	0.0198	0.0080	0.0030	0.1672	0.0259	0.0078	0.0062	0.0043	0.0080	0.0005	0.0467	Do. with 1 per cent. of gypsum.
L²	7.3	600	0.1013	0.0424	0.0228	0.0267	0.0080	0.0090	0.2042								Do. with 2 per cent. of gypsum.
M	9.3	30	0.0530	0.0272	0.0167	0.0008	0.0080	0.0072	0.1197								M cement.
M¹	9.3	300	0.0699	0.0363	0.0167	0.0148	0.0047	0.0083	0.1397								Do. with 1 per cent. of gypsum.

5. It is greater with new cement, and least with that which has been kept in stock.

6. It is increased by the admixture of gypsum.

7. Other experiments show that it is greatest with over-limed or highly-burned cements, and that all cements contract when drying, and expand on being put into water.

The expansion was progressive for a year, and amounted to 0.09 of 1 per cent. to 0.21 for the neat cements without gypsum; and to 0.01 to 0.06 of 1 per cent. for the mixture with three parts sand. With gypsum the figures went up to $1\frac{8}{10}$ per cent. and 0.47 per cent. respectively.

In comparing the results from this table with the previous one, it should be borne in mind that these experiments are on English Portland cements, and those of the former table on German and French cements.

Those of Table No. 3, the later ones, do not agree very closely with the earlier ones given in Table No. 4, as published at the time by the Messrs. Dykerhoff.

For example, the average coefficient of expansion for pure Portland cement determined from nine different kinds, 16 weeks old, is by Table No. 3, .000408, which represents the percentage of its length that the average specimen expanded immersed in water.

By Table No. 4, under the same conditions the average coefficient of expansion for pure Portland cement determined from nine different kinds of cement is .000991, or more than double that of Table No. 3.

By Table No. 4 the average coefficient of expansion for Portland cement-mortars, 1 part cement, 3 parts sand by weight, 16 weeks old, immersed in water, is .000221, while by Table No. 3 it is .000067 for the same kind of mortars.

Therefore for pure Portland cements the average coefficients from Table No. 3 are less than half of those which are taken from Table No. 4, while for cement-mortars the average coefficients from Table No. 4 are about three times those taken from Table No. 3.

This variation in the comparison of the average results derived from the two tables throws some doubt over the accuracy of the whole experiments, and makes it quite a fair question whether the errors incidental to the smallness of the measurements and the size of the specimens do not make tabulated expansion of little value in exact calculations for practice.

The great benefit really conferred upon engineering science by these

very careful experiments, made with apparatus especially designed to remove and compensate for most of the errors peculiar to all fine measuring instruments, appears to be in the general deductions that we can make with reasonable assurance of their being accurate, such as the facts that are the same in both tables and are in accord with "the experience of practice" to quote Mr. Faija's expression on this question.

The most salient of these facts are:

First.—That all pure Portland cements and Portland cement-mortars when left in the air, contract from the second day after gauging, onward through at least four months, and probably more.

Second.—All pure Portland cements and Portland cement-mortars when immersed in water, expand from the second day after gauging onward through at least one year.

Third.—All pure Portland cements, after gauging, expand and contract more than when mixed with sand.

Fourth.—All pure Portland cements and Portland cement-mortars contract much more when left in the air than they expand when immersed in water.

While these general facts are pretty clearly proven, the experiments (in a similar manner to those made on the expansion and contraction of cement-mortars when exposed to changes of temperature) show elements of doubtfulness when we endeavor to deduce from these coefficients to be used in designing work,

For example: A monolithic wall, 1 000 meters long, made of cement-mortar (1 part Portland cement, 3 parts sand), between abutments supposed to be immovable, and immersed in water, would, at the expiration of twelve months from the date of its construction, and independently of temperature changes, increase its length about 0.31 meters (12.2 inches), according to Table No. 4, or nearly the same as it would after undergoing a change of temperature of 54 degrees Fahrenheit according to coefficients from M. Bouniceau, "Annales des Ponts et Chaussées," 1863. (See Transactions Am. Soc. C. E., Vol. XIV., page 495.) Now most engineers familiar with walls of this character would be quite unwilling to accept the above expansions, derived though they are from careful experiments on small specimens, in the light of "the experience of practice."

The same wall, as stated above, if instead of being built in water had been allowed to harden in the air, would at the expiration of four months, according to Table No. 3, have contracted about 0.98 meters

(38.5 inches), independently of all changes in volume due to tempera-
ture changes. This deduction is still more at variance with our expe-
rience than the preceding.

Mr. Henry Faija, in his work on cement, entitled " Cement for
Users," last edition, 1884, discusses Table No. 4, and vainly endeavors to
reconcile it with the record of all large concrete works, such as the New
Victoria Docks, where the vertical cracks indicate contraction, and yet
by Table No. 4, expansion is shown in all cases.

This difficulty would have entirely disappeared if Mr. Faija had seen
Bauschinger's later experiments as embodied in Table No. 3, where
contraction is shown in every case for mortars in *air;* just as *expansion*
is shown in every case for mortars in water by Table No. 4.

In this connection the experience of the Department of Docks of
New York gives important information. Over ten years ago, when the
upper portion of the new bulkhead walls, built of Portland cement con-
crete, began to extend over considerable distances in monolithic masses,
vertical cracks began to appear at irregular intervals. To remedy this
difficulty, vertical joints were placed in the masonry as it was built,
at intervals from 150 to 200 feet apart. These joints have opened about ¾
of an inch, and do not seem to be affected by temperature changes.
They have also stopped the irregular vertical cracks from appearing.*
As about half of the concrete in this part of the wall is alternately wet
and dry by the action of the tide, about one-fourth is immersed all the
time, and about one-fourth is out of water all the time; the resultant
contraction, that undoubtedly takes place, is the component of the
forces of contraction and expansion which occur sometimes together
and sometimes separately as the wall is submerged by the tide.†

Although so much prominence has been given of late years to the
economy of employing beton and concrete in large quantities in mono-
lithic structures, very little notice has been taken by engineers of the
serious effects of contraction on all concrete work that hardens in the
air. The makers of artificial stone pavements, after innumerable fail-

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* If a mean be taken of the changes in 12 months time in air or water, we have 38.5
—12.2 = 13.1 inches contraction. A wall 1 000 meters, or 3 936 feet, is equal to say twenty
lengths of 200 feet. And if one such length contracts ¾ inch as mentioned, twenty would
contract 15 inches.

† After the earth filling is deposited in rear of the wall to grade, it is doubtful if any of
the concrete is ever dry below high-water mark, on account of the absorption and retention
of the tide-water.

ures, soon found that the contraction of the cement in setting could only be successfully resisted by the introduction of joints properly arranged, and where these joints are not used in large concrete construction, trouble is sure to be experienced. In the building of fourteen large kilns for burning cement, about three years ago, concrete made of Rosendale cement was employed. In the plan the kilns were built in one piece of concrete masonry, about 50 by 20 by 150 feet, with the necessary openings and arches. Shortly after construction and use serious cracks appeared, and rendered necessary extensive repairs which were never satisfactory. If vertical joints had been properly placed, no trouble would have arisen. The Vanne Aqueduct in France is another case in point of engineers employing beton and concrete without provision for contraction. This aqueduct, mentioned by General Gillmore in his work entitled " Béton Agglomèré," as an example of the successful application of beton and concrete in monolithic construction, was built about twenty years ago, and is now, according to the testimony of French engineers, in bad condition. Cracks have appeared in so many places, and are still appearing, that the leakage question has become a very serious one. In addition to this several of the large *beton coignet* arches have been propped up by building cut-stone masonry arches underneath them to prevent their fall.

In this case, in the light of our advance in knowledge of the material of which the aqueduct is built, it seems reasonably fair to suppose that if vertical joints had been introduced over the piers at suitable distances, few of the cracks now so troublesome would have appeared.

With regard to failure of the arches, while contraction unprovided for might be an important factor in the case, the French engineers ascribe it to the use of *beton coignet*.

A series of experiments now in progress show that both Portland and Rosendale cements, when mixed neat, absorb about the same amount of water as when mixed with two parts sand, and the absorption is probably least for that proportion of cement which just fills the spaces in the sand. Since the expansion of cement-mortars hardening under water is greatest when neat cement is used, it is possible that there is some connection between absorption and expansion. This might also explain the greater contraction of neat cement-mortars.

These results are sufficient to show that the quantities involved, while of no importance to structures of moderate expansions, may become of

very great moment when great heights or great lengths of masonry are involved.

The unexplored region is that pertaining to the important changes occurring during the first 48 hours after· mixing; the question as to whether the changes are the same during induration, whether occurring under pressure or not; and the investigation of nearly the whole range of changes which occur in our native cements.

All experiments in this direction should be on sufficiently large specimens to eliminate small errors in observation, and all circumstances of temperature and moisture should be completely observed.

The Committee therefore ask to be continued.

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